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INVESTIGATION OF THE FEASIBILITY OF USING THE DISCRETE ADDRESS BEACON SYSTEM DATA LINK FOR NON-ATC COMMUNICATIONS

FINAL REPORT

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The present, proposed near future, and possible future communication traffic is identified. DABS models for uplink traffic, downlink traffic, and message scheduling are developed and exercised over a broad spectrum of conditions for both en route and terminal area communications.

A simulation is performed to determine the probable delays due to queuing for the various levels of implementation and with various numbers of aircraft.

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SUMMARY

ARINC Research Corporation is under contract to the Federal Aviation Administration (Contract DOT-FA76WA-3788) to assist in the development and evaluation of technical and cost factors that will affect the upgraded third-generation air traffic control system. One effort under this contract was an investigation into the technical feasibility of utilizing the Discrete Address Beacon System (DABS) data link as a means of transmitting the airline industry's private communications.

The airline industry maintains constant contact with aircraft in flight through voice communications over private facilities owned and operated by the industry. The system currently operates in a voice mode between the aircraft and ground and in a low-speed data mode for ground distribution. Efforts are now under way to convert a large portion of this total communications traffic to digitized data format. Three categories of communications traffic were analyzed: (1) those required for immediate implementation, (2) those suitable for near-future implementation, and (3) those considered possible for long-range implementation.

The purpose of this study was to investigate the suitability of the DABS to support airline industry private communications. The first step was to develop a comprehensive data base describing the different types of candidate messages, with their arrival rate, length, purpose, and implementation time. After characterizing the communications load in this manner, it was necessary to analyze the behavior of DABS over the projected range of message traffic. This analysis required the development of models that would predict message service time as a function of the number of aircraft, aircraft range, message length, message arrival rate, radar rotation rate, and pulse repetition frequency.

DABS models for uplink traffic, downlink traffic, and message scheduling were exercised over a broad spectrum of conditions for both en route and terminal area communications. The principal output of these runs was the time available for company communications and the expected message service time. These data were then used in simulation runs to determine the probable delays due to queuing for the various levels of implementation and with various numbers of aircraft.

The results of the simulation show that DABS capacity in terminal areas is more than sufficient to meet company communications requirements under foreseeable conditions. The en route system would also perform adequately under most of the projected traffic conditions, but the ability of DABS to provide en route private communications would be marginal under the worst-case scenario evaluated. If all of the foreseeable services associated with this worst case were implemented by all certified air carriers and densities approached levels in which 15 air carrier aircraft appeared in a 4° DABS radar beam, then communications delays of about 12 seconds could be expected. Furthermore, increases in traffic load beyond this point would rapidly lead to severe degradation of the system.

This study assumed that all nonsurveillance DABS communications capacity could be dedicated to private air carrier use. However, if the DABS data link capability were also used for ATC-associated information dissemination, a combined traffic load would result. This would reduce the number of aircraft that each DABS site could accommodate for company communications or generate message arrival delays in excess of those presented in this study.

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CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) has sponsored the development of the Discrete Address Beacon System (DABS) to meet the surveillance and communications requirements of the air traffic control system serving the expanding aviation population in the national airspace. Although developed to provide improved surveillance, the DABS design incorporates a powerful data link capability between the ground and individual aircraft. Advocates of the DABS concept have proposed that the data link be utilized for nominal exchange of flight-following information, intermittent positive control (IPC) functions, and, eventually, most communications traffic between aircraft and ground systems.

Primary users of the air traffic control (ATC) system are the certified air carriers. They are expected to retrofit their aircraft with any new system that will improve flight safety and optimize the efficient operation of the ATC system. However, in addition to handling ATC-associated communications, the air carrier community maintains and operates a large communications network in support of company traffic requirements. The air carriers view the development of a data link for company communications as a major element in their efforts to reduce unnecessary duplication of operating procedures, increase flight status and scheduling efficiency, and combat increasing operating costs. For similar reasons they are understandably reluctant to implement or support the development of airborne devices or systems that are under- or overdesigned or provide unnecessary redundant capability. However, there have not been any detailed investigations as to whether the capability provided by the DABS data link can support the operational service required by the commercial air carriers.

The Office of System Engineering Management (OSEM) of the FAA, recognizing the concern and hesitancy of the commercial air carrier industry to support the development of systems with questionable impact on ATC or air carrier operations, has initiated an effort with ARINC Research Corporation (Contract DOT FA76WA-3788) to perform an objective communications requirements study addressing the company communications that could be handled on a DABS data link. This report reviews the characteristics of company (i.e., commercial air carrier) communications and evaluates the potential transmission of these communications over the DABS link on the basis of an

analytical model of the channel-management procedures inherent in the DABS data link. The evaluation assesses (by phase of flight) the level of digital company communications capable of being implemented on the DABS data link and identifies possible methods for interfacing the FAA communications system and the commercial air carrier communications system.

1.2 CONTRACT SCOPE AND OBJECTIVES

The DABS data link capability analysis for company communications is one part of a five-task contract that addresses a variety of alternative concepts for upgrading the present air traffic control system. The overall contract effort entails the development and analysis of performance and cost factors in the following five task areas:

- Task I - Avionic Alternatives for Selected ATC System Development
- Task II - Selective Address Beacon System
- Task III - VHF Data Link
- Task IV - DABS/IPC Impact on Air Carriers
- Task V - FAA Communications Modernization Program

This report, concerned with Task IV, documents the analysis of the capability of the Discrete Address Beacon System (DABS) to serve as a data link for commercial air carrier communications. The objective of Task IV is to evaluate the ability of DABS to handle the traffic load of digital company communications. The task includes identification of the functional modules required to interface FAA and company communication centers.

1.3 PROJECT OVERVIEW

The project is structured to determine the capability of the DABS data link to handle the family of digital traffic typical of present and future company communications. A key requirement in the study was the development of the characteristics of digitized company communications. This development of characteristics was based on both current company communications operations and predicted future uses of a commercial air carrier data link. To facilitate evaluation of the DABS capability, several mathematical models were developed to handle the scheduling algorithms of DABS. These models were based on a series of constraints and assumptions derived from currently proposed channel-management and scheduling algorithms for the DABS concept. The ensuing analyses evaluated the capability of DABS to support varying levels of air carrier communications workloads. The results of the analyses provided sufficient details of message delay times and communications traffic patterns to identify possible configurations of FAA/commercial air carrier interfaces at a functional module level.

1.4 REPORT ORGANIZATION

The technical details of DABS operation and company communications are presented and evaluated in Chapters Two through Six. For the convenience of a reader interested primarily in the findings of the study, Chapter Seven covers the results in a summary form.

The details of the data development and approach used in this study are presented in Chapter Two, which addresses the air carrier industry's development of digital company communications and identifies the flexibility and constraints involved in the use of the DABS concept. The philosophy of the developed analytical method is also briefly discussed in this chapter.

Chapter Three is a discussion of the requirements and characteristics of airline digital communications. Both current voice and proposed future digital communications are identified and classified as to their probable occurrence during flight, frequency (arrival rate), and typical text length. Possible message formats for each message type are developed on the basis of the expected mode of entry (automatic or manual) and whether the message is in a fixed text format or in a free, unformatted text.

Chapter Four is concerned with the current DABS concept and its use as an air carrier data link. The various interrogation and reply formats employed by DABS are summarized, together with a brief discussion of the DABS channel-management and scheduling algorithms. The chapter develops in detail the characteristics of the Comm-C and Comm-D formats (i.e., the two data link communications formats of DABS) and their use in Extended-Length Messages (ELMs). Assumptions concerning the operation of the DABS concept are presented and used in formulating the DABS channel-management and scheduling models to be used in the DABS data link capacity analysis of Chapter Five.

Chapter Five uses the results of Chapters Three and Four to determine the DABS company communications capability at various levels of implementation representing both terminal and en route areas. The effect of various parameters such as radar beamwidth, radar rotation rate, aircraft ranges, and company message lengths on the DABS data link performance are discussed.

Chapter Six presents the operational interface procedures and functional descriptions of the equipment involved in the DABS company communications interface facilities. The interfaces are developed only in enough detail to permit recognition and discussion of interface problems resulting from both the uplink and downlink requirements of company communications.

Chapter Seven summarizes the results of the investigation, and Chapter Eight presents specific conclusions derived from the analyses performed.

CHAPTER TWO

BACKGROUND AND STUDY APPROACH

The interest of the air carrier industry in digital data communications was fostered by the increasing demand on the present voice circuits for exchange of information between aircraft in flight and supporting ground operations. A similar requirement for improved surveillance and more efficient air traffic control was identified by the FAA, and this resulted in the development of the DABS concept. The data link inherent in the DABS concept offers a possible solution to both of these communications needs through digitized communications between aircraft and ground operations -- provided sufficient capacity exists in the DABS to meet the needs of both communities.

This chapter provides the background for the development of digital company communications, highlights the features of the DABS operation, and identifies the approach used in the study for evaluating the ability of DABS to handle the digital company communications workload. Although a total evaluation of DABS capability must include the proposed future uses of the data link for ATC functions, this study considers the surveillance mode of DABS with its built-in tactical data link as the only ATC application of DABS and assumes that the lengthier communications modes (Comm-C and Comm-D) would be totally available for company communications traffic.

2.1 COMMERCIAL AIR CARRIERS' INTEREST IN DIGITAL DATA LINK APPLICATIONS

The following historical account of data link developments within the airline industry is presented to provide an understanding of the air carriers' commitment to improving the efficiency of communicating routine company messages. The efforts of the various participants in the data link developments provide the basis for well structured and defined communications requirements, which will be used in evaluating DABS ability to handle company communications.

For more than 20 years the Airlines Electronic Engineering Committee (AEEC)* has been monitoring and initiating studies into the technical feasibility and possible operational uses of a digitized ground-air-ground communications data link. The commercial air carriers' interest in digital communications evolved from the industry's desire to obtain high-reliability and high-quality ATC communications and to support various company communications activities. Initially, air carriers emphasized the need to provide improved ATC handling of aircraft and avoid the predicted "eventual saturation of the VHF aeronautical band". However, these problems of early ATC operations and VHF usage were solved by the technical innovations of the ATC Radar Beacon System (ATCRBS) transponder and reduced VHF channel spacing. The concept of digital communications, although not always a prominent issue, was to be investigated cooperatively and independently by the airlines and governmental departments, agencies, and committees throughout the subsequent years.

During this period, the dramatic growth of commercial and general aviation resulted in the development of two classes of traffic and a communications network for each. The increasing need for FAA supervision and monitoring of all aircraft activities resulted in the ATC system. This system currently monitors aircraft movements, vectors and controls all IFR and some VFR aircraft, and provides constant navigational and meteorological information for all interested aviation classes. Increased commercial air carrier activity caused the number and type of company communications (which support operational efficiency and resource scheduling/monitoring) to increase dramatically over the years. The commercial air carriers, in response to these increases in communications workloads and more stringent time requirements on communications, have constantly expanded and enhanced their own ground-air-ground communications network.

Currently the communications between aircraft and company ground facilities is handled through the ARINC network of ground VHF aeronautical radio stations. The ARINC network covers the continental U.S. flight paths of all commercial airlines; it is configured of centrally located manned stations that are connected to a number of automated remote VHF receiving and transmitting stations. The communications traffic distribution requirements of ground-air and air-ground messages are handled through the ARINC Electronic Switching System (ESS), which electronically connects the ARINC system to a number of airline facilities. However, an ARINC operator is currently required in the interface between the digital ground network and the air-ground voice communications system.

Recent air carrier interest in data link has been generated by the predicted potential savings due to automatic reporting and improved efficiency of airline operations resulting from the use of a digital ground-air communications data link. The current efforts of the air carriers are directed towards providing a digital data link over the current VHF

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*AEEC is a standing committee of the Airline Communications Administrative Council (ALCAC) associated with Aeronautical Radio, Inc. (ARINC).

frequencies of air and ground communications. This link will operate with compatible data-transfer characteristics to ensure compatibility with the existing digital ground network. The primary objective of this system is the near-term automation and digitizing of some of the current flight-following company communications. However, the system is also designed for growth to handle new types of company communications, if and when the needs arise. The company communications data link is designed to serve the commercial air carriers exclusively, and efforts are being made to develop message types and message services that will alow more efficient use of the resources available to the air carrier industry. Capabilities desired in the company data link include the following:

- Reduction of pilot and ARINC operator workload
- More rapid distribution of company communications
- Provision of information sufficient to improve flight-following procedures (and hence flight scheduling and the scheduling of operational maintenance)
- Provision of permanent copy of flight operational data or other information in a manner that involves less interruption of other, more critical flight deck activities
- Ability of the communications data link to operate with high communications reliability and provide continuous radio coverage of the areas of concern (i.e., to avoid the annoying and time-comsuming duplication of messages due to loss of contact)
- Direct interface of the data link with the current ground digital network

2.2 DABS CONCEPT AND THE POTENTIAL USE OF DABS IN COMPANY COMMUNICATIONS

Concurrently with the commercial air carrier industry's investigation of possible company communications data links, the FAA was investigating and developing various concepts to improve surveillance and traffic control. One of these concepts, DABS, was concerned with both improving the quality of surveillance data and providing separation assurance. To meet these objectives, the DABS had to become a combined transponder and data link.

The DABS has been developed to coexist with the present secondary surveillance radar (SSR)-ATCRBS transponder system during the transitional phases involving the DABS ground site and avionics implementation. The DABS ground interrogators are designed to elicit standard SSR-ATCRBS replies from ATCRBS transponder units and to obtain replies from DABS transponders using discrete interrogation. The DABS transponders will reply to both ATCRBS ground interrogators in ATCRBS format and DABS interrogators in DABS format. The ability of the DABS interrogator to discretely initiate replies from aircraft is accomplished through the assignment and use of individual aircraft address codes over the data link inherent in the DABS concept. These discrete surveillance interrogations are scheduled by the DABS ground facility to ensure eliminating the receipt of overlapping replies (i.e., the occurrence of mutual interference known as "synchronous garble").

Analytical investigations and predictions have shown that the increased quality of surveillance data inherent in DABS will result in a much lower utilization of the surveillance frequencies (i.e., 1030 MHz for interrogations, 1090 MHz for replies) than with the current SSR system. It has been proposed that the DABS ability to discretely address aircraft be used, together with the additional time, to provide a digital data link between ground-based systems and the aircraft. Numerous communications services have been proposed as candidates for transmission over the DABS data link. Primary candidates for implementation during system surveillance are separation-assurance Automated Traffic Advisories and Resolution Service (ATARS) commands and certain ATC data.* However, the additional time provided by the DABS concept will also permit extended digital communications between air and ground. It is this capability that will be examined as a possible method for conducting company communications.

The implementation of company communications over the DABS data link must meet both the air carrier's requirements on a company data link and the design constraints of the DABS concept. The requirement for interfacing with the existing company ground digital network will necessitate the use of standard 7-level character teletype coding for all text elements of company communications. This technical requirement will be merged with the characteristics of the DABS data link (e.g., channel management, message format, etc.) to determine the DABS data link capacity for company communications. The other air carrier requirements for a company data link are concerned mostly with operational factors and are reflected in message characteristics (e.g., pilot display, cabin teletype, etc.).

2.3 TECHNICAL APPROACH OF THE STUDY

The approach developed during the study combines both analytical and simulation techniques to determine the capacity of the DABS data link to handle various predicted levels of digital company communications. The major elements of this approach were (1) to define company communications traffic loads, (2) to develop a DABS communications transaction model, (3) to develop a queuing model for the system, and (4) to analyze the behavior of the system under the forecast traffic loads. Figure 2-1 illustrates the overall study approach.

The digital company communications characteristics (i.e., text content, message length, message arrival rate, message input mode, etc.) were developed by a data collection and analysis process involving both actual traffic data of the current ARINC system and future company communications digital requirements. Digital data link company communications traffic scenarios were developed by identifying probable message services and their expected relative time of implementation on a data link (i.e., immediate, future, and possible future implementation).

*ATC communications composed of ATC VHF voice frequency, altitude, heading, and airspeed data are known as ATC tactical communications.

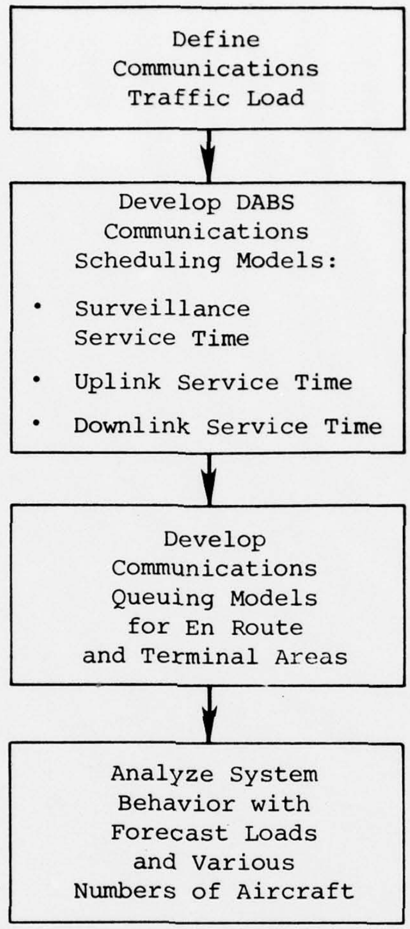

Figure 2-1. STUDY APPROACH

Detailed models of the DABS communications protocol were developed concurrently to investigate the relationship between message transmission time and radar rotation rate, pulse repetition frequency, number of aircraft, aircraft range, and message length. These models also provided estimates of the time available for company communications during each radar scan.

The final step in the analysis procedure was to combine the time available per scan, the service time, and the expected traffic load in an event-by-event simulation of message flow through the system. The time required to transmit each message was recorded by the simulation and subsequently averaged to obtain the mean waiting time with a given scenario. The simulation was also used to determine maximum loading possible before catastrophic deterioriation in transmission times occurred.

CHAPTER THREE

DEVELOPMENT OF DIGITAL COMPANY COMMUNICATIONS MESSAGE SERVICES AND CHARACTERISTICS

Current communications of the air carrier industry are handled through the ARINC VHF aeronautical radio network. The implementation of a digital company communications data link will increase the air carriers' capability in many communications service categories over the capability possible with the current system design. This chapter develops typical expected message services and characteristics of future digital company communications from an extensive data base of company communications information. Message service characteristics provided by the current company network as well as future service characteristics are discussed. Message types, expected text content and length, message arrival rates, and the direction of the information flow (uplink or downlink message) are developed for digital company communications use from the data base sources. These message characteristics are developed from consideration of the following:

- The probable relative period of implementation of a message type on a company communications data link (immediate, future, and possible future implementation)
- The mode of operation of the on-board data link device (whether the message information is to be automatically sensed and reported, initiated through brief manual commands with a fixed format, or initiated through manual commands of a long and/or unformatted nature)
- The assigning of the message occurrence to either terminal area or en route flight operation and procedures

3.1 DATA BASE OF COMPANY COMMUNICATIONS

The data sources for both current voice and future digital company communications services and characteristics consist of both extensive historical technical documentation and a large number of airline, AEEC, and ARINC personnel who are and have been closely involved in communications operations and planning. The major and most current sources, as well as actual records of company communications, have been used in this study to develop the characteristics of digital company communications.

3.1.1 Present-Day Company Communications Traffic

At present, an ARINC operator converses with the flight crew and either sets up direct telephone patches to company personnel (e.g., at maintenance or operations centers) or effects digital communications with the company via the ARINC ESS. The latter method is by far the most prevalent.

A composite of an actual two-day period of domestic communications traffic load has been assembled. Composed of approximately 14,000 air-ground contacts, it is representative of the voice company communications being generated and processed by today's system. The investigation of this traffic indicated that most communications involved in the current system are of a flight-following nature, with the predominant flow of information being air-to-ground. These messages were found to have a relatively short, somewhat standard content, as opposed to the less frequent maintenance or logistic message services, which represent much longer, nonstandard "free talk". A limited sample of "passenger service" communications was observed, usually dealing with medical emergencies or lost property. The sample was insufficient to establish probable message formats for this service category.

The results of this data study, together with the operational procedures and requirements involved in the various message services, are presented in Section 3.2.1, in which current company communications characteristics are discussed.

3.1.2 Future Digital Company Communications Message Services

Major documentation of the future uses of a company digital data link was reviewed and interviews were held with AEEC members, ARINC, and ARINC Research personnel who are involved in and familiar with the plans for future company communications operations. The information thus obtained was used in conjunction with the current company communications functions to develop and postulate four distinct digital company communications message services. The following data were developed for each of these future digital message services: the expected message types, message content or expected message length, and various operational characteristics (e.g., message generation rate, typical phase of flight for message occurrence, identification of message input and display mode.)

3.2 DIGITAL COMPANY COMMUNICATIONS SERVICES AND CHARACTERISTICS

The analysis of the company communications data base has identified four message service categories and the representative message types contained in each. It has been found that not all of the future air-ground company transactions are scheduled for implementation on a digital data link. Messages of unusual content or urgent nature (e.g., critical maintenance problems, passenger emergencies, etc.) will continue to be handled by voice communications. This section concentrates on company messages that are expected to or could eventually be digitzed and implemented on a data link. Message types and the associated message characteristics are developed for each company communications message service. The

use of a digital data link for company communications implies the standardization of the format and content of company messages. Therefore, the text of a candidate message, although perhaps inconsistent with a particular air carrier's current messages, contains most of the information transferred by the air carrier industry for this message type. For each message type, it includes a sufficient number of characters to allow for the transmission of the company flight identifier (e.g., PA 1111) and a set of routing characters indicating message type and distribution requirements.

The use of a digital data link for company communications has been proposed as a means of decreasing the pilot's overall workload and time spent in company communications transactions. The current planning of company message services and types exhibits an awareness of this fact through the identification of three modes of inputting and displaying company communications data available to the airborne unit. Digital company communications traffic is expected to be automatically sensed and reported without human intervention, initiated through brief manual commands in fixed format, or initiated through long commands that are formatted or unformatted. The latter would require an on-board teletype or similar input device. The former two modes can be implemented through the use of a more compact device of limited input and display capability. Table 3-1 identifies these three modes of message input and display; it will be referred to frequently in subsequent developments of company communications characteristics.

Table 3-1. ON-BOARD INPUT AND DISPLAY MODES

Mode	Information Characteristics
1	Input data are automatically sensed and reported without human intervention. Output is brief; either it is continuously displayed or a hard copy is provided.
2	Input requires brief manual intervention to generate a fixed format message. Output is continuously displayed or a hard copy is provided.
3	Input and output require considerable intervention by crew members. Input and output can be long and formatted or long, unformatted "free text".

The following subsections present the message types, their characteristics, and the probable relative data link implementation schedule for company communications message services in the areas of flight following, maintenance and logistics, and passenger service.

3.2.1 Flight-Following Company Communications Characteristics

Flight-following messages are those related to the current or planned movement of the aircraft and to crew status (planning and performance) and weather advisory reports. The following messages are in this category:

- Departure/Arrival Reports (i.e., Out-Off-On-In, or OOOI, reports)
- In-Range Reports and Gate Requests
- En Route Position Reports
- Estimated Time of Arrival (ETA) Reports
- Weather Advisory Reports
- En Route Flight Plan Revision Advisories
- Flight and Ground Delay Reports
- Gate Assignments
- Flight Conditions
- Crew Planning
- Crew Physiological and Performance Monitor

The occurrence of these message types can be correlated directly to the aircraft's phase of flight (i.e., terminal or en route). Messages typically being generated while the aircraft is operating within a terminal area are the Departure/Arrival Reports, In-Range Reports, Gate Requests, Ground Delay Reports, and Gate Assignments. The information flow for all these messages except the Gate Assignment is from the aircraft to the ground facility. The Ground Delay Reports and Arrival Reports are the only two message types that are expected to occur when the aircraft is on the ground. The remaining flight-following message types occur typically during the en route portion of a commercial air carrier flight.

Table 3-2 identifies, by terminal and en route phase of flight, the message type, text content, input and display mode (see Table 3-1), probable text length (given in characters based on standard 8-bit characters of 7-bit ASCII code plus parity), frequency of occurrence of such messages, and direction of the information flow (uplink or downlink).

3.2.2 Operation and Maintenance Communications Characteristics

The routine operation of air carriers requires the reporting of certain conditions or cabin parameters. Typical of these types of communications are:

- Seat occupancy information
- Connecting flights
- In-flight service shortage
- Customer comforts

Table 3-2. FLIGHT-FOLLOWING DIGITAL COMPANY COMMUNICATIONS CHARACTERISTICS

Message Type	Input Display Mode (see Table 3-1)	Text Content*	Information Flow Direction	Arrival Rate	Text Length* (Characters)
Terminal Area Company Communications					
Departure	2	Departure Aerodrome, Fuel on Board, Out Time, Off Time, Destination Station ETA, Altimeter Setting	Downlink	1/flight	51
Arrival	1	Arrival Aerodrome, Fuel on Board, On Time, In Time	Downlink	1/flight	35
In-Range and Gate Request	2	Arrival Aerodrome, Fuel over Destination, Altimeter Setting, Gate Assignment Request	Downlink	1/flight	31
Ground Delay	2	Departure Aerodrome, Fuel on Board, Boarded Fuel, Out Time, Estimated Time of Departure	Downlink	1/flight	65
Gate Assignments	1	Company Flight Identifier, Destination Station, Arrival Runway, Assigned Gate	Uplink	1/flight	23
En Route Area Company Communications					
En Route Position or ETA	1 or 2	Departure and Destination Stations, ETA, Present Position, Fuel on Board, Fuel Endurance, Cruising Level, Cruising Speed, Next Reporting Time (complete text content not always sent)	Downlink	1/10 flights	61
Flight Delay	2	Departure Aerodrome, Fuel on Board, Out Time, Off Time, Fuel Endurance, ETA	Downlink	1/10 flights	60

*Text content and length includes company flight identifier and routing indicator on all message types.

(continued)

Table 3-2. (continued)

Message Type	Input Display Mode (see Table 3-1)	Text Content*	Information Flow Direction	Arrival Rate	Text Length* (Characters)
En Route Area Company Communications (continued)					
Weather Advisories	3	Departure and Destination Stations, Cruising Level and Speed, Present Position, Dew Point, Sky Conditions, Static Air Temperature, Surface Temperatures, Turbulence Altimeter Settings, Icing	Downlink	1/hour	165
En Route Flight Plan Revisions	2	Departure and Destination Stations, Fuel on Board, Fuel Endurance, Present Position, Cruising Level and Speed for Alternate Routing and/or Aerodromes	Downlink	1/5 flights	120
	2	Company Flight Identifier, Alternate Aerodrome, Next Reporting Position	Uplink	1/5 flights	70
Flight Conditions	3	Departure and Destination Stations, Fuel on Board, Present Position, free-text communicating miscellaneous company parameters	Downlink	1/flight	150
Crew Planning	3	Departure and Destination Stations, Fuel on Board, Present Position, ETA, free-text communicating company crew member planning and scheduling	Downlink Uplink	1/flight 1/flight	200 (max) 600
Crew Physiological and Performance Monitoring	1	Departure and Destination Station, Fuel on Board, formatted physiological data on each member of the flight crew	Downlink	1/4 hours	600

*Text content and length includes company flight identifier and routing indicator on all message types.

These messages are normally transmitted during the en route portion of a flight to allow scheduling of corrective actions prior to arrival of the aircraft at its destination.

Maintenance messages are periodic, automatically sensed, and reported at various intervals of flight to allow ground monitors to track the condition of certain aircraft parameters such as:

- Airframe parameters
- Engine parameters
- System parameters

Typical frequencies of occurrence dictate reporting maintenance characteristics during departure, en route, and arrival periods, resulting in a communications workload in both the terminal and en route areas.

The results of the analyses of the company communications data base for the operation and maintenance message services are presented in Table 3-3, with the expected frequency of occurrence during a routine flight.

3.2.3 Passenger Service Company Communications Characteristics

Passenger service messages of company communications include the transactions involved in querying about or securing a reservation for airlines, hotels, or other ground services, as well as air-ground passenger communications. An estimated 10 percent of the passengers will be using one or more of these services during a given flight. Considering the processing time involved with such services, these communications must be restricted to the en route portions of flight only. Table 3-4 summarizes the typical data characteristics of this message service and the associated message types.

3.2.4 Digital Company Communications Implementation Approach

As in the implementation of any nationwide project, the digitalization of company communications on a data link is expected to occur on an evolutionary basis. The conversion to digital communications will be guided by the relative economic benefits. However, the current study has required an estimate of the likely implementation of digital company communications; thus upon examination of the company communications data base, a preliminary division of the message types across a relative implementation time period was developed. The message types have been catalogued as candidates for immediate, future, or long-range implementation on a company communications data link. Table 3-5 lists the message types and identifies their expected relative implementation time frame on a digital data link.

The message types listed under "Immediate Implementation" are the predominant message types currently being handled by voice communications and occupying the attention of flight crew members during high-activity

Table 3-3. OPERATION AND MAINTENANCE DIGITAL COMMUNICATION CHARACTERISTICS

Message Type	Input Display Mode (see Table 3-1)	Text Content*	Information Flow Direction	Arrival Rate	Text Length* (Characters)
		Terminal Area Company Communications			
Airframe Parameters	1	Departure and Destination Stations; and various aircraft structural measurements automatically monitored and reported	Downlink	2/flight	100
Engine Parameters	1	Departure and Destination Stations; and various engine parameters such as rpm, oil pressure, vibration, temperature in turbines, etc.	Downlink	2/flight	100
System Parameters	1	Departure and Destination Stations; and parameters such as hydraulic pressure, oxygen used, hydraulic fluid used, etc.	Downlink	2/flight	100
		En Route Area Company Communications			
Seat Occupancy/ Flight Connections	2	Departure and Destination Aerodromes, ETA, Souls on Board, list of connecting flights	Downlink	2/flight	180
Customer Comforts	3	Departure and Destination Aerodromes; and free text communicating cabin repairs, logistics of food, beverages, films, books, toilet usage, etc.	Downlink	1.5/flight	200
Maintenance	1	See Company Communications Terminal Area	Downlink	4/hour each	100 each

***Text content and length includes company flight identifier and routing indicator on all message types.**

Table 3-4. TYPICAL PASSENGER SERVICE DIGITAL COMMUNICATION CHARACTERISTICS

Message Type	Input Display Mode (see Table 3-1)	Text Content*	Information Flow Direction	Arrival Rate	Text Length* (Characters)
En Route Area Company Communications					
Reservation Query	3	Passenger Name, Reservation Number, Payment Method, and particulars of the reservation (flight date, airline and flight, class, etc.)	Downlink	40/flight	100
Reservation Acknowledgment	3	Flight Identifier; Reservation Number; and indication of available, not available, repeat	Uplink	40/flight	10
Reservation Confirmation Request	3	Confirm (or Clear), Flight Identifier, Reservation Number	Downlink	40/flight	15
Reservation Confirmation Acknowledgment	3	Confirmed (or cleared) and repeat reservation data	Uplink	40/flight	95
Customer Communications (Air-Ground)	3	Passenger Name, Contact Point, and free-text (i.e., "will arrive Los Angeles TWA flight number xxx, have car waiting, make appointment with...")	Downlink	20/flight	200

*Text content and length includes company flight identifier and routing indicator on all message types.

Table 3-5. RELATIVE IMPLEMENTATION OF MESSAGES ON A COMPANY COMMUNICATIONS DATA LINK			
Message Type	Direction	Flight Phase	Number of Characters
Immediate Implementation			
Arrival	Downlink	Terminal	35
In-Range	Downlink	Terminal	31
Departure	Downlink	Terminal	51
Delay	Downlink	Terminal	65
Gate Assignment	Uplink	Terminal	23
En Route (Position)	Downlink	En Route	61
Delay	Downlink	En Route	60
Future Implementation			
Airframe	Downlink	Terminal and En Route	100
Engine	Downlink	Terminal and En Route	100
System	Downlink	Terminal and En Route	100
Flight Plan Revision Advisory	Downlink	En Route	120
Flight Plan Revision Acknowledgment	Uplink	En Route	70
Weather Advisory	Downlink	En Route	165
Crew Planning	Downlink	En Route	200
Crew Planning	Uplink	En Route	600
Flight Conditions	Downlink	En Route	150
Possible Long-Range Implementation			
Crew Physiology and Monitoring	Downlink	En Route	600
Seat Occupancy Flight Connection	Downlink	En Route	180
Customer Comforts	Downlink	En Route	200
Reservation Query	Downlink	En Route	100
Reservation Acknowledgment	Uplink	En Route	10
Reservation Confirmation Request	Downlink	En Route	15
Reservation Confirmation Acknowledgment	Uplink	En Route	95
Customer Communication	Downlink	En Route	200

periods of flight. The data for the Arrival, In-Range, and Departure Reports are in many instances already automatically sensed and reported to the flight deck. These data, as well as the information necessary for the remaining company communications in this category, are considered readily adaptable to data link application through relatively simple avionics additions or modifications for digital transmissions.

The message types classified for future implementation are those requiring more complex avionics, new instrumentation, crew training, or the use of an on-board teletype (or similar device). The data link implementation of this second group of messages will complete the digitizing of almost all the current voice communications between air and ground facilities. The implementation of the third category of message types is contingent on both link capacity and expected usage. These possible future message types are composed mostly of customer-associated communications and are viewed as potentially economically beneficial to air carriers if sufficient usage develops.

These three levels of digital company communications will be used in subsequent chapters to analyze the capability of the DABS data link to sustain various possible levels of digital company communications traffic that could be generated by the commercial air carrier industry.

CHAPTER FOUR

MODELING THE DABS CONCEPT

The analysis of company communications on DABS involves a thorough understanding of the channel-management process. This process has been developed to accommodate surveillance functions in both the ATCRBS and DABS modes, provide ATC tactical data on a priority basis, and utilize the data link capability associated with other data exchange between an aircraft in flight and the ground support facility. Proper management of the time in which an aircraft is visible to the DABS is critical if optimum efficiency of DABS is to be realized. This chapter is devoted to the development of the tools required to analyze the operation of DABS in performing the various functions of surveillance and communications.

Three models have been developed to describe the channel-management process: (1) a surveillance transaction model, which computes the time required to complete surveillance functions; (2) an uplink Extended Length Message (ELM) transaction model, which computes the service time for uplink company communication; and (3) a downlink ELM transaction model, which computes the service time for downlink company communications. A fair degree of sophistication was incorporated into these models in order to investigate the effects of such factors as number of aircraft in the beam, range and separation of aircraft, antenna rotation rates, transmission rates, and message lengths.

This chapter describes each of the models used in terms of the scheduling algorithms required for implementing company communications via DABS. These descriptions are preceded, in Section 4.1, by a background review of ATCRBS and DABS operating characteristics relevant to an understanding of the remaining sections as well as Chapter Five.*

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*The reader unfamiliar with the basic details of ATCRBS and DABS should consult the following articles:

1. "The Development of the ATC Radar Beacon System, Past, Present, and Future," *IEEE Transactions on Communications,* May 1973, Paul R. Drouilhet, Jr.
2. *DABS: A System Description,* Lincoln Laboratory Report ATC-42, FAA Report RD-74-189, November 1974, P.R. Drouilhet.

4.1 GENERAL CHARACTERISTICS OF ATCRBS AND DABS

An aircraft within the coverage area of DABS is visible for a fraction of the antenna revolution time. This dwell time is primarily dependent on the antenna rotation rate and the width of the beam of coverage and is the only time available for communication. While visible, the aircraft receives a number of ATCRBS interrogations requesting transponder replies of identity and altitude. A fixed repetition rate of these interrogations, known as the Pulse Repetition Frequency (PRF), determines the number of times an aircraft is interrogated by ATCRBS during the beam dwell time. An ATCRBS interrogation elicits responses from all visible aircraft. Each "All Call" interrogation requires a listening time equal to the time required to receive a reply from an aircraft at maximum range; the total time for an interrogation and all responses is called an ATCRBS period. Any unused time between the end of one ATCRBS period and the beginning of the next is called a DABS period; this time is available for DABS discrete interrogations and company communications. The structure of a typical dwell time of an aircraft is shown in Figure 4-1.

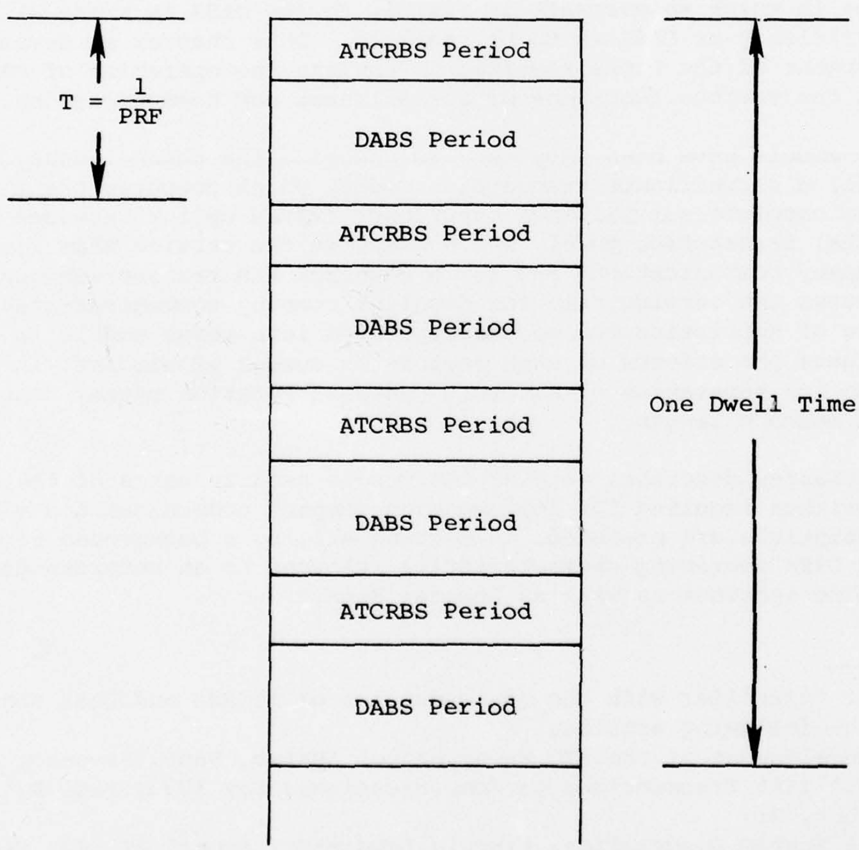

Figure 4-1. DABS OPERATION IN AN AIRCRAFT'S DWELL TIME

An aircraft may start or finish its dwell time during a portion of a DABS or ATCRBS period. However, the ground computer maintains the position and range of each aircraft and thus can determine the best time to interrogate an aircraft successfully.

Any transmissions from any aircraft are the direct result of a ground interrogation. This interrogation may produce one or more replies from the aircraft; and each interrogation, coupled with the resulting replies, comprises a transaction. A list of transactions in a DABS period is always planned before the period occurs to allow optimum utilization of the link by minimizing dead times; this list is called a schedule. Details regarding the algorithms utilized in scheduling are addressed in Section 4.3.

ATCRBS All-Call interrogations fall into the two basic types. The Mode A interrogation of 10.3 μs duration elicits replies containing the identity of the responding aircraft. The Mode C interrogation of 23.3 μs duration performs a different function by eliciting replies that contain information about the altitude of an aircraft. In actual implementation, a scheme has been defined to interlace the altitude and identity transactions.

DABS transactions, as defined by the Channel Management document, ATC-43, fall into the four basic types shown in Table 4-1. The Type 1 transaction is the 56-bit DABS-Only All-Call, which elicits a reply indicating aircraft transponder display capabilities from DABS-equipped aircraft (as opposed to a modified ATCRBS All-Call, in which all aircraft respond). The Type 2 transaction is the 56-bit Surveillance-Only transaction, in which a discrete interrogation elicits a response that contains altitude or identity information as well as an indication of any Extended Length Message that is waiting to be sent from the aircraft. The Type 3

Table 4-1. TRANSACTION TYPES

Type Number	Transaction Types	Length in Bits	Uplink Interrogation Name	Downlink Interrogation Name
1	DABS-Only All-Call	56	All-Call Interrogation	All-Call Reply
2	Surveillance	56	Surveillance Interrogation	Surveillance Reply
3	Surveillance/ Short Message	112	Comm-A	Comm-B
4	Long Message	112	Comm-C	Comm-D

transaction consists of a 112-bit interrogation and 112-bit response which contain all of the surveillance data in Type 2 plus a 56-bit message. The last type is designed to efficiently transmit and receive Extended Length Messages of up to 16 bursts of 112 bits each.

The models described in this chapter are concerned with message Types 2, 3, and 4 since all aircraft are assumed to be equipped for ATCRBS and DABS operation initially.

4.2 DABS TRANSACTION CHARACTERISTICS

For the purposes of this study, it was assumed that all aircraft would be equipped for both DABS and ATCRBS operation. This assumption represents a "worst case" situation under which the adequacy of DABS for handling company communications can be evaluated.

Of the different message types, the Type 3 transaction (shown in Figure 4-2*) is the simplest. It consists of an interrogation and a single reply separated by a dead time in which the link is not utilized. The dead time consists of the propagation delay between the ground and the aircraft, the message processing time, and the propagation time from the aircraft to the ground antenna.

In the Type 4 transaction, there are two varieties -- one for uplink ELMs and one for downlink ELMs. In either case, up to 16 transmissions are made, each containing a segment that is a fraction of the total ELM.

In the uplink case, the ground transmits these segments sequentially; when the transmission of all segments has been completed, the ground instructs the aircraft to reply, indicating any segments that should be retransmitted because of errors. When all segments have been received correctly by the aircraft, the ground initiates a transaction that clears the message buffer in the aircraft's transceiver. The entire process is illustrated in Figure 4-3.

In the downlink case, up to 16 segments may be sent from an aircraft. The ground commands the aircraft to transmit a number of segments, less than or equal to the number of segments waiting in the aircraft's message buffer, during the time remaining in the DABS period. If the ground detects an error in any of the segments, it requests a retransmission of those segments. When all segments have been correctly received by the ground, it initiates a transaction to clear the aircraft's buffer. A hypothetical series of transactions is illustrated in Figure 4-4.

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*All of the figures in this chapter show signal timing at the DABS interrogator site. The ground-to-air transmissions are shown above the baseline, while air-to-ground transmissions are shown below the line.

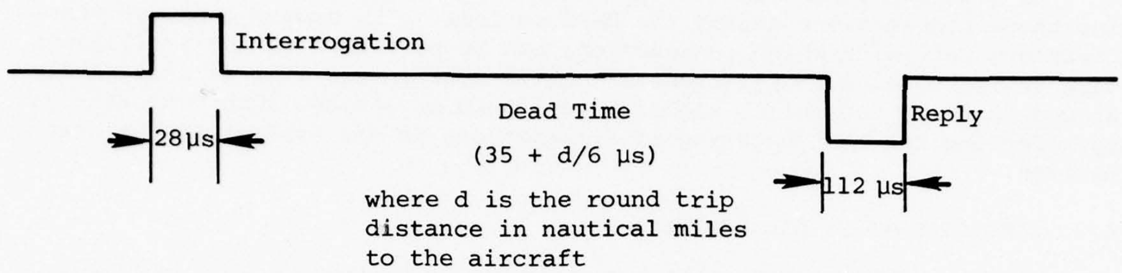

Figure 4-2. SURVEILLANCE/SHORT MESSAGE TRANSACTIONS

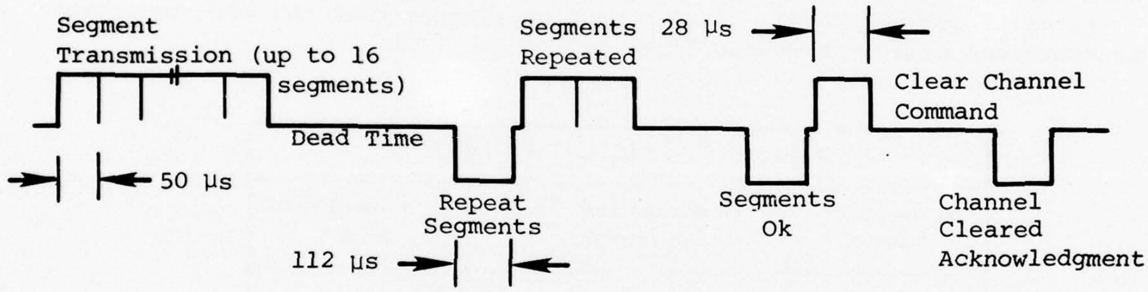

Figure 4-3. UPLINK ELM TRANSACTIONS

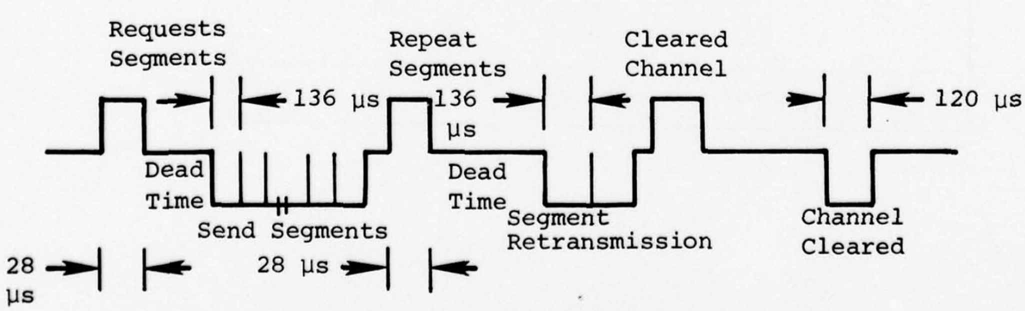

Figure 4-4. DOWNLINK ELM TRANSACTIONS

As previously mentioned, only a limited amount of time is available for these transactions during the DABS periods. The ground computer must therefore determine which transactions can be performed in the available time and must schedule the transactions to utilize the link as effectively as possible. A scheduling algorithm designed to achieve such efficiencies by selecting the best ordering of transactions is the subject of the next section.

4.3 DABS PRIORITIES AND ASSUMPTIONS

The scheduling algorithm is concerned with allocating the available time in a DABS period to the many different types of messages. This allocation is accomplished by a message priority system with four allocation levels, as shown in Table 4-2. Priority surveillance transactions (those relevant to emergency situations) are scheduled first in the available time; if all can be accomplished, normal surveillance transactions (altitude and identity) are scheduled. The process continues until all transactions in each of the allocation levels have been completed or until the available time has been exhausted. Should the time be insufficient, then in the next DABS period the allocation process begins again for level 1 (priority surveillance). This scheme guarantees that the most important transactions will be executed first.

Table 4-2. ALLOCATION LEVELS

Allocation Level	Description of Function	Transmission Type*
1	Priority Surveillance	Not Considered
2	Normal Surveillance	Type 3
3	Uplink Extended Length Messages	Type 4
4	Downlink Extended Length Messages	Type 4

*For the purpose of this study.

The models described in the following sections were created on the basis of the requirements of the proposed Channel Management Process and certain specific assumptions:

- The ATCRBS period is calculated on the assumption of the longest interrogation time (that of Mode C), which is 23.2 μs.
- Only two message transaction types occur: (1) those which include surveillance and a 56-bit message, and (2) those which are for ELMs. Therefore, all altitude/identity transactions are Type 3 and all company communications are Type 4.
- Only Extended Length Messages carrying company communications will be considered.
- The link is a perfect medium; no errors occur in the transmission or reception of any message, and thus no transactions will be repeated.
- No priority surveillance messages will occur; all surveillance transactions are for altitude and identity only.

4.4 THE SCHEDULING MODELS

Scheduling techniques were developed to achieve the most effective utilization of the communication link for the three types of transactions considered (surveillance, uplink ELM, and downlink ELM). These techniques were modeled and used with a group of simplifying assumptions to determine the service times for a given set of parameters.

The first of the required models is the surveillance transaction model, which computes the time required to complete all surveillance functions. Once this is computed, the time available for company communications can be determined. Two additional models are then required to calculate how much of this available time is required for an uplink message (the uplink ELM transaction model) and how much is required for a downlink message (the downlink ELM transaction model). These service times are then used by the queuing model described in Chapter Five to estimate the expected delay. Functional descriptions of the transaction models are presented in the next three subsections.*

4.4.1 The Surveillance Transaction Model

The surveillance transaction model created for use in this study is a computer program that schedules discrete interrogations to a group of aircraft in accordance with the proposed channel-management algorithms. The model calculates the service time necessary for surveillance transactions for a maximum of 15 aircraft in the beam with any distribution of ranges less than 200 nautical miles. The events modeled by this program are described in the following paragraphs.

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*Appendixes A, B, and C contain a description of the programs used for these models.

Surveillance transactions are the simplest transactions in structure, consisting of one interrogation and one reply (see Figure 4-2). The dead time separating the two messages is equal to 35 μs (aircraft transponder message-processing time) plus the propagation delay of the message traveling in both directions. Instead of permitting a dead time for each transaction to go unused, a scheduling scheme was developed to utilize this time; the result of this process is shown in Figure 4-5.

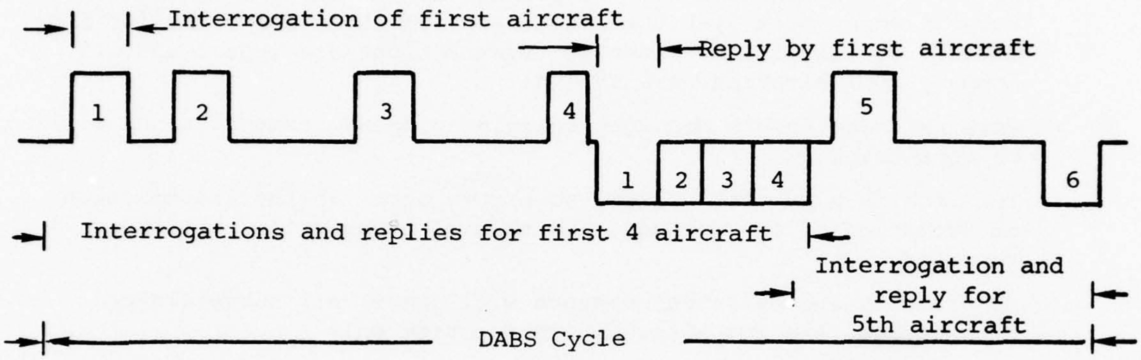

Figure 4-5. MULTIPLE SURVEILLANCE TRANSACTION TIMING INFORMATION

The first transaction is scheduled, on the basis of the ground computer's knowledge of the range of the aircraft, by predicting the time at which the reply will be received by the ground antenna. The computer then attempts to schedule another transaction by placing the second reply at the end of the first reply and then predicting when the second interrogation should be transmitted. If the interrogation does not overlap a previous interrogation or reply, the second transaction is scheduled to occur, and the process is repeated until no more transactions can be scheduled or no more transactions are pending. The list of schedule transactions constitutes a cycle. Additional cycles may be created to complete the schedule for a given DABS period if sufficient time remains.

The efficiency resulting from this scheduling technique depends on the ranges of the individual aircraft in the beam and the dwell time. The ground computer implements this technique by using the range data on active aircraft to schedule pending transactions in the order of decreasing aircraft range.

4.4.2 The Uplink ELM Transaction Model

The uplink ELM transaction model is a computer program that schedules uplink ELMs to a group of aircraft in the beam. The model calculates the service time necessary to transmit one uplink ELM of up to 99 segments to each of a maximum of 15 aircraft in the beam with any distribution of ranges less than 200 nautical miles. The details of this process are described in the following paragraphs.

As shown in Figure 4-3, the structure for uplink ELM transactions consists of two phases. In the first phase message segments are transmitted to the aircraft. The ground will transmit as many as possible in the time available; if all of the segments to be transmitted cannot be sent in one schedule, then the remaining segments will be attempted in the next. When the last segment is transmitted, the aircraft responds with a reply indicating which segments were incorrectly received; then the ground repeats the transmission of the improperly received segments and elicits a response from the aircraft. This process continues until the aircraft indicates to the ground that all segments have been received properly. At this point, the second phase starts. A command from the ground instructs the aircraft to clear its ELM buffer, and the aircraft sends a reply acknowledging completion of the process.

All uplink ELM transactions for one aircraft must be completed before uplink ELMs to the next aircraft are scheduled. Thus the next aircraft is handled only when the clear-channel transaction has occurred.

The data input to the model includes the number of uplink segments (maximum of 99) that must be transmitted to each aircraft plus the range of each aircraft. Though DABS is designed to accommodate a maximum of 16 segments per ELM, more segments can be associated with a message if they are handled in groups of 16. Thus long company communications can be implemented in bursts of up to 16 segments.

4.4.3 Downlink ELM Transaction Model

The downlink ELM transaction model is a computer program that schedules downlink ELMs from a group of aircraft in the beam. The model calculates the service time necessary to transmit one downlink ELM of up to 99 segments from each of a maximum of 15 aircraft in the beam with any distribution of ranges less than 200 nautical miles. The function of this model is described in detail below.

The structure of downlink ELM transactions, as shown in Figure 4-4, is similar in concept to that of the uplink, since both consist of two phases. In the first phase, the ground interrogates the aircraft and requests a number of ELM segments to be sent by the aircraft sequentially, one every 136 μs. The number requested may be the total number of segments in the aircraft's buffer, or it may be limited to the number that the ground can receive in the time remaining in the DABS period; in the latter case, this process is repeated in the next schedule until all segments have been received. The ground then interrogates the aircraft if any segments need to be repeated. If those segments are received properly, the ground instructs the aircraft to clear its buffer, and the aircraft replies indicating that it has done so; this completes phase two.

The clear interrogation and reply must both occur before any downlink ELM segments can be transmitted from another aircraft. The scheduling of multiple downlink ELM transactions from different aircraft in order to minimize dead time is therefore not possible.

CHAPTER FIVE

ANALYSIS OF DABS COMPANY COMMUNICATIONS CAPACITY

This chapter describes the methodology used in applying the DABS company communications capacity models and presents the analyses of both terminal area and en route communications for various levels of DABS implementation.

The various communications elements presented in previous chapters are brought together in this chapter for the quantitative development of DABS company communications capacity.

5.1 METHODOLOGY

A number of quantitative measures can be applied to describe the capacity of DABS for handling company communications. The most useful of these, however, is the expected time a message would spend in the system waiting and being served. In order to determine this "time in queue," three major elements are required: (1) a description of the probable communications load, (2) a model of the DABS communication link that computes utilization and service times, and (3) a queuing model that estimates the time in queue on the basis of the required service times and the available time for communications. The basic procedure for estimating DABS capacity is outlined in Figure 5-1. Because of the technical nature of the analysis involved, it will be useful to refer to this figure for an understanding of how each mathematical development fits into the study.

5.1.1 Company Communications Load

The first major element in the DABS analysis is the estimate of company communications load. This load must be defined in terms of the number of characters per message and the message arrival rate. Chapter Three identified the basic company communications and developed the digital characteristics associated with each type of message. Table 5-1 presents the digital message characteristics when converted to the

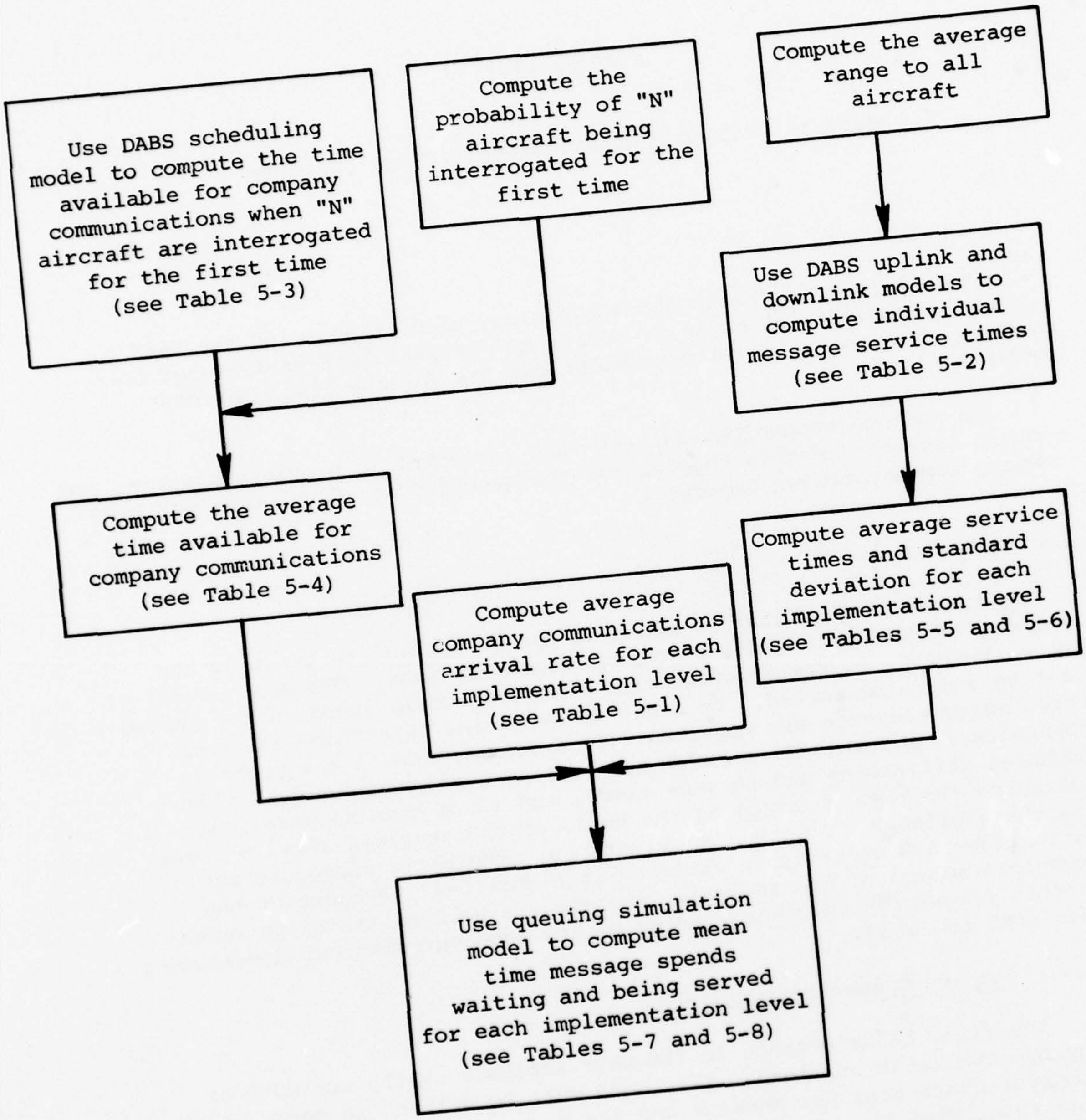

Figure 5-1. GENERAL METHODOLOGY FOR DETERMINING DABS CAPACITY

Table 5-1. CHARACTERISTICS OF COMPANY DATA COMMUNICATIONS					
Message Type	Link	Flight Phase	Number of Characters	Frequency* per Aircraft (f_i)	Number of ELMs
Immediate Implementation (I)					
Arrival	DN	Terminal	35	1	4
In-Range	DN	Terminal	31	1	4
Departure	DN	Terminal	51	1	6
Delay	DN	Terminal	65	1	7
Gate Assignment	UP	Terminal	23	1	3
En Route	DN	En Route	61	0.1	7
Delay	DN	En Route	60	0.1	6
Future Implementation (II)					
Airframe	DN	Terminal	100	1	10
Airframe	DN	En Route	100	0.5	10
Engine	DN	Terminal	100	1	10
Engine	DN	En Route	100	0.5	10
System	DN	Terminal	100	1	10
System	DN	En Route	100	0.5	10
Flight Plan Revision	DN	En Route	120	0.2	12
Flight Plan Revision	UP	En Route	70	0.2	7
Weather Advisory	DN	En Route	165	1	17
Crew Planning	DN	En Route	200	0.1	20
Crew Planning	UP	En Route	600	1.1	60
Flight Condition	DN	En Route	150	1	15
Possible Long-Range Implementation (III)					
Crew Physiology	DN	En Route	600	0.5	60
Seat Occupancy/ Flight Connection	DN	En Route	180	2	18
Customer Comfort	DN	En Route	200	1.5	20
Reservation Query	DN	En Route	100	40	10
Reservation Confirmation	DN	En Route	15	40	2
Reservation Acknowledgment	UP	En Route	10	40	1
Reservation Confirmation Acknowledgment	UP	En Route	95	40	10
Customer Communication	DN	En Route	200	20	20

*Assumes typical flight lasts 2 hours for en route communications.

DABS ELM format. The mean arrival rate, for a group of messages, was computed from the following relationship:

$$E(\eta) = \sum f_i / D$$

where

$E(\eta)$ = the mean arrival rate
f_i = the frequency (from Table 5-1)
D = the duration of the flight phase

The table reflects three implementation levels used in the present study: (I) immediate implementation, (II) future implementation, and (III) long-range implementation. It is also important to note whether a particular message is sent up to the aircraft or down to the ground since the transmission rates and priorities are different. Basic differences in the operation of terminal and en route radar systems necessitate distinguishing between the terminal and en route phases of a flight in describing the traffic load offered.

The size of a message is influenced by whether the message is generated manually or automatically. Automatically generated messages are rigidly formatted and subject to data compaction; manually entered messages, on the other hand, frequently contain free text and vary considerably in length. Each message is transmitted as a number of segments by DABS, each segment comprising 80 bits. Thus a given segment contains up to 10 characters in the 8-bit ASCII code used by the airline industry.

Message arrival rates are described in terms of frequency per flight. For the purpose of this analysis, it was assumed that the en route portion of a typical flight is 2 hours and that the terminal phases of each flight are 20 minutes. Using a longer terminal time would have the effect of decreasing traffic load. Decreasing the duration of the en route time, however, tends to have a somewhat smaller impact on the arrival rate since some messages are sent periodically and others are sent once per flight.

5.1.2 DABS Communications

This section describes the procedure used to compute channel utilization and service times for company communications. Descriptions of the DABS communications transaction models used for this purpose were presented in Chapter Four; experimentation with these models confirmed the following facts about the behavior of the DABS communications link:

- Increasing the pulse repetition rate decreases the time available for company communications because a fixed amount of time is required for surveillance.
- Decreasing the radar beamwidth decreases the time available for company communications because the aircraft is "painted" for a shorter time.

- Increasing the rotation rate of the radar decreases the time available for company communications because scheduling inefficiencies prevent full utilization of the available time.
- The time required for a given message to be transmitted (service time) is proportional to aircraft distance.
- The average service time for a given-length message increases as the number of messages increases, because of the intervening ATCRBS transmissions and rotational delays.
- The time available for company communications decreases as the number of aircraft interrogated increases and as the aircraft range increases.
- The order of transmission affects the average service time when more than one aircraft has a message to send. The reason for this is that a certain amount of unused time remains in a given interrogation cycle whenever the "clear" response at that particular range is postponed until the next cycle. Since the average message arrival rate in most cases was less than one message per scan, this slight increase in average service time may be safely ignored.
- Service times increase rapidly with an increase in the number of segments transmitted. This nonlinear relationship is due to interruptions from ATCRBS interrogations and inefficient scheduling of the "clear" response.

As a result of these observations, it was determined that the service time should be computed for each message type. The mean service time and its variance could then be estimated on the basis of the frequency of each message type. Thus the mean service time is given by

$$E(t_s) = \sum_{i=1}^{K} f_i \; t_i \Big/ \sum_{i=1}^{K} f_i$$

where

$E(t_s)$ = the mean service time

t_i = the service time for message type i

f_i = the frequency for message type i

i = the index of summation

The variance of service times is given by:

$$S^2(ts) = \left[\left(\sum_{i+1}^{K} f_i \; t_i^{\,2} \Big/ \sum_{i=1}^{K} f_i\right)\right] - E^2(t_s)$$

where S(ts) is the biased estimate of the standard deviation.

Since the service time is dependent on the number of aircraft, the DABS link was analyzed for a number of aircraft densities: 1,2,3,4,6,8,10, 12, and 15 aircraft within the radar beam at a given instant. This encompasses the probable range of aircraft densities that could appear in a 4° radar beam at any given instant for either en route or terminal radars. Fifteen aircraft in a 4° beam corresponds to 1350 aircraft within the area of radar coverage if it is assumed that the aircraft are randomly distributed throughout the airspace.

Service time is also dependent on aircraft range. For the en route analysis, aircraft were assumed to be evenly spread throughout a 200-nautical-mile corridor. The average range to these aircraft was therefore 100 nautical miles. In the terminal analysis, however, aircraft were given decreasing separations as they approached the radar. This assumption reflects the tendency for aircraft to concentrate near the airport terminal as their speeds decrease. A simple relationship that achieves this type of distribution is given by

$$R_k = \frac{(k)\ (k + 1)\ d}{(N)\ (N + 1)}$$

where

R = the range to aircraft k

N = the total number of aircraft

d = the maximum range (60 nautical miles)

k = 1,2,3,4,....,N

The average distance to all aircraft derived from the above is

$$E(R_N) = \frac{(N + 2)\ d}{3N}$$

where $E(R_N)$ is the mean range to N aircraft. The mean calculated in this manner tends to produce shorter service times (and therefore potentially fewer queuing delays) than an even distribution of aircraft over the same distance. Since the service time is nearly proportional to range, the use of the mean range for both en route and terminal communications is justified.*

Table 5-2 summarizes the results obtained from the DABS model for each scenario analyzed. It shows, for example, that an en route uplink message with 60 ELMs requires 0.026255 second if there are 15 aircraft in the beam. With only one aircraft, the time is reduced by 13 percent to 0.022843 second. A downlink en route message of the same length requires 0.027392 second with 15 aircraft in the beam. This is slightly longer than the uplink message because of the difference in data rates and

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*The resulting error was less than 1 percent in all cases tested.

Table 5-2. SERVICE TIME FOR A MESSAGE AS A FUNCTION OF NUMBER OF AIRCRAFT AND NUMBER OF ELMs

Number of ELMs	Number of Aircraft Mean Distance (nm) Mean Distance (nm)	 Terminal En Route	1 60 100	2 40 100	3 33 100	4 30 100	6 27 100	8 25 100	10 24 100	12 23 100	15 23 100
Service Time for Uplink Message (in seconds)											
3		Terminal	.001973	.001479	.001306	.001232	.001158	.001109	.001084	.001059	.001059
1		En Route	.002862	.002862	.002862	.002862	.002862	.002862	.002862	.011421	.011421
7		En Route	.003162	.003162	.003162	.003162	.003162	.003162	.011421	.011421	.011421
10		En Route	.003312	.003312	.003312	.003312	.003312	.003312	.011421	.011421	.012843
60		En Route	.022843	.022843	.022843	.022843	.023012	.024833	.024833	.024833	.026255
Service Time for Downlink Message (in seconds)											
4		Terminal	.002262	.001768	.001596	.001521	.001447	.001398	.001373	.001348	.001348
6		Terminal	.002534	.002040	.001867	.001793	.001719	.001670	.001645	.001620	.001620
7		Terminal	.002670	.002176	.002003	.001929	.001855	.001806	.001781	.001756	.001756
10		Terminal	.003078	.002584	.002411	.002337	.002263	.002214	.002189	.002164	.002164
2		En Route	.002979	.002979	.002979	.002979	.002979	.002979	.002979	.011421	.011421
6		En Route	.003523	.003523	.003523	.003523	.003523	.011421	.011421	.011421	.013115
7		En Route	.003659	.003659	.003659	.003659	.003659	.011421	.011421	.011421	.013251
10		En Route	.004067	.004067	.004067	.004067	.011421	.011421	.011421	.012979	.013659
12		En Route	.004339	.004339	.004339	.004339	.011421	.011421	.011421	.013251	.013931
15		En Route	.004747	.011421	.011421	.011421	.011421	.011421	.013115	.013659	.014339
17		En Route	.012843	.012843	.012843	.012843	.012843	.012979	.013387	.013931	.014611
18		En Route	.012979	.012979	.012979	.012979	.012979	.013115	.013523	.014067	.014747
20		En Route	.013251	.013251	.013251	.013251	.013251	.013387	.013795	.014339	.016304
60		En Route	.024339	.024339	.024339	.024339	.024339	.024475	.024833	.026712	.027392

slightly different channel-management procedures. It is assumed that all DABS surveillance interrogations are Comm-A's, which results in somewhat longer service times than may actually be obtained in practice. It is also assumed that all aircraft are DABS-equipped. (A decrease in the number of DABS-equipped aircraft would increase available communications time.)

In addition to the service times shown in Table 5-2, it is also necessary to know the time available for company communications during each scan. This time varies with the pulse repetition frequency and the radar rotation rate as well as the number of aircraft to be interrogated and their range. The DABS surveillance transaction model described in Chapter Four was used to compute the time available, "t_a", for a number of scenarios. The results are presented in Table 5-3, which shows that an en route radar with 15 aircraft has no more than 0.00176 second available for ELM transmissions between ATCRBS interrogations, while a terminal radar has about 0.00535 second of available time. The difference is principally due to the difference in propagation times involved. For en route aircraft, propagation time equivalent to a 400 nautical-mile-round trip is allowed for a response after each ATCRBS interrogation. Propagation time equivalent to 120 nautical miles was allowed for the terminal analysis. These delays assume that transponder responses from more distant aircraft would not occur frequently enough to result in significant error rates due to synchronous garbling (i.e., the overlapping of DABS communications with distant ATCRBS replies).

The actual amount of time available during each revolution of the radar depends on the pulse repetition frequency, the speed of rotation, and the beamwidth. For a terminal radar at 15 rpm with a 4° beam and PRF of 100, there are four hits per revolution, while an en route radar at 5 rpm will "paint" each aircraft at least 12 times per revolution. Thus the total time available during a scan is 4 or 12 times the values shown in Table 5-3 depending on the type of radar.

Calculating the time available in this manner, however, unnecessarily penalizes DABS company communications capacity since DABS surveillance interrogations are required only when an aircraft is first acquired during a scan. Other aircraft in the same 4° sector may or may not be included in the first DABS surveillance interrogation, depending on their azimuthal separations within the 4° beam. Since the scheduling of additional DABS interrogations in subsequent hits can significantly reduce the time available for company communications during a scan, the present analyses considered a probable distribution of aircraft within the beam. It is assumed that a given aircraft is equally likely to appear on any hit during the scan. Thus, if "r" is the maximum number of aircraft in any 4° sector, and "n" is the number of hits per aircraft, the probability of painting "k" of these aircraft for the first time on a given hit is

$$P_k = \frac{r!\,(1 - n^{-1})^{r-k}}{(r - k)!\; k!\; n^k}$$

Table 5-3. TIME AVAILABLE FOR ELMS BETWEEN ATCRBS SURVEILLANCE INTERROGATIONS (ALL TIMES IN SECONDS)

Number of Aircraft*	En Route (Maximum Range = 200 nm)			Terminal (Maximum Range = 60 nm)		
	Time Used for ATCRBS	Time Used for DABS	Time Available for ELMs (t_a)	Time Used for ATCRBS	Time Used for DABS	Time Available for ELMs (t_a)
0	0.00252	0.00000	0.00748	0.00079	0.00000	0.00921
1	0.00252	0.00265	0.00483	0.00079	0.00092	0.00829
2	0.00252	0.00276	0.00472	0.00079	0.00103	0.00818
3	0.00252	0.00288	0.00460	0.00079	0.00133	0.00788
4	0.00252	0.00300	0.00448	0.00079	0.00140	0.00781
6	0.00252	0.00370	0.00378	0.00079	0.00196	0.00735
8	0.00252	0.00414	0.00334	0.00079	0.00249	0.00672
10	0.00252	0.00450	0.00298	0.00079	0.00267	0.00654
12	0.00252	0.00509	0.00239	0.00079	0.00329	0.00592
15	0.00252	0.00572	0.00176	0.00079	0.00386	0.00535

*This is the number of aircraft interrogated by DABS for the first time during a scan.

Since the time available for company communications during a given hit is dependent on the number of aircraft hit for the first time (see Table 5-3), the expected value of time available as a result of aircraft dispersion is given by the relation

$$E(ta) = n \sum_{k=o}^{r} P_k \, t_k$$

where

r = maximum number of aircraft in the beam

n = number of times an aircraft is hit during one scan

t_k = time available for company communications with "k" aircraft being hit for the first time (from Table 5-3)

P_k = probability of "k" aircraft being hit for the first time

$k = 1,2,3,\ldots,r$

$E(ta)$ = mean time available for company communications with "r" aircraft randomly dispersed in the beam

The computed values of E(ta) corresponding to various scenarios are given in Table 5-4. Note that the actual time available for en route communications with 15 aircraft is 0.0658 second, which is about three times greater than the predicted time (0.00176×12) from Table 5-3.

5.1.3 Queuing Model

A commonly used and accepted measure of communications system performance is the expected delay due to traffic queuing. This section considers message service times and time available for message transmission to determine probable delays when company communications are transmitted on DABS. A number of analytical models were used in an effort to approximate the mean time messages spent waiting and being served. The least sophisticated of these models was the classical single-server queuing formula developed by Khintchine and Polloczek.* In addition, formulas for queues with multi-priority categories as well as formulas for priority categories with preemptive-resume priority queuing discipline were tried. All of these models proved disappointing under moderately heavy traffic conditions. The relatively poor performance under these conditions is primarily due to the nonrandom arrival process associated with the period during which the aircraft is not in the radar beam. Further difficulties are encountered if ATCRBS and DABS surveillance functions are included in the analysis since there are no provisions in the classical models for mixing fixed-length and variable-length messages.

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*James Martin, *Systems Analysis for Data Transmission*. Englewood Cliffs, New Jersey: Prentice-Hall, 1972, P. 423.

Table 5-4. MEAN TIME AVAILABLE FOR COMPANY COMMUNICATIONS		
Number of Aircraft	Time Available for Company Communications During a Single Scan (in seconds)	
	Terminal	En Route
0	0.0368	0.0898
1	0.0359	0.0871
2	0.0352	0.0847
3	0.0347	0.0824
4	0.0342	0.0804
6	0.0334	0.0768
8	0.0328	0.0737
10	0.0323	0.0710
12	0.0318	0.0686
15	0.0311	0.0658

In order to estimate the magnitude of waiting times with reasonable accuracy under all loads, an event-by-event simulation was employed. The inputs to this model consisted of the mean service time, E(ts); the mean message arrival rate E(n); the time required for a complete rotation of the radar (4 or 12 seconds); and the time available during each rotation for company communications, ta. Figure 5-2 outlines the basic operation of the simulation.

The simulation used in this analysis generates messages at random times with the expected arrival rates shown in Table 5-1. These messages are queued for an appropriate period corresponding to the rotational delay of the radar. As many messages as possible are sent during the available time, and any remaining are held for a 4-second period in the terminal simulation or a 12-second period for the en route simulation. The simulation is run the equivalent of 1000 or more transactions in order for the computed averages to stabilize. A cross-check of the model was obtained after each run by comparing the required arrival rate to the simulated arrival rate. On the basis of this comparison, the delays measured are typically within 10 percent of the true value. The running time of the simulation was minimized by using the mean service time, E(ts), rather than the actual distribution of service times from Table 5-2.

Values of E(ts) as well as S(ts) and the mean message arrival rate are shown in Tables 5-5 and 5-6. They were computed from the data in Tables 5-1 and 5-2 by weighting the various service times according to message frequencies in each implementation phase. Each phase combines the traffic requirement of all previous phases. The standard deviation of service times in all

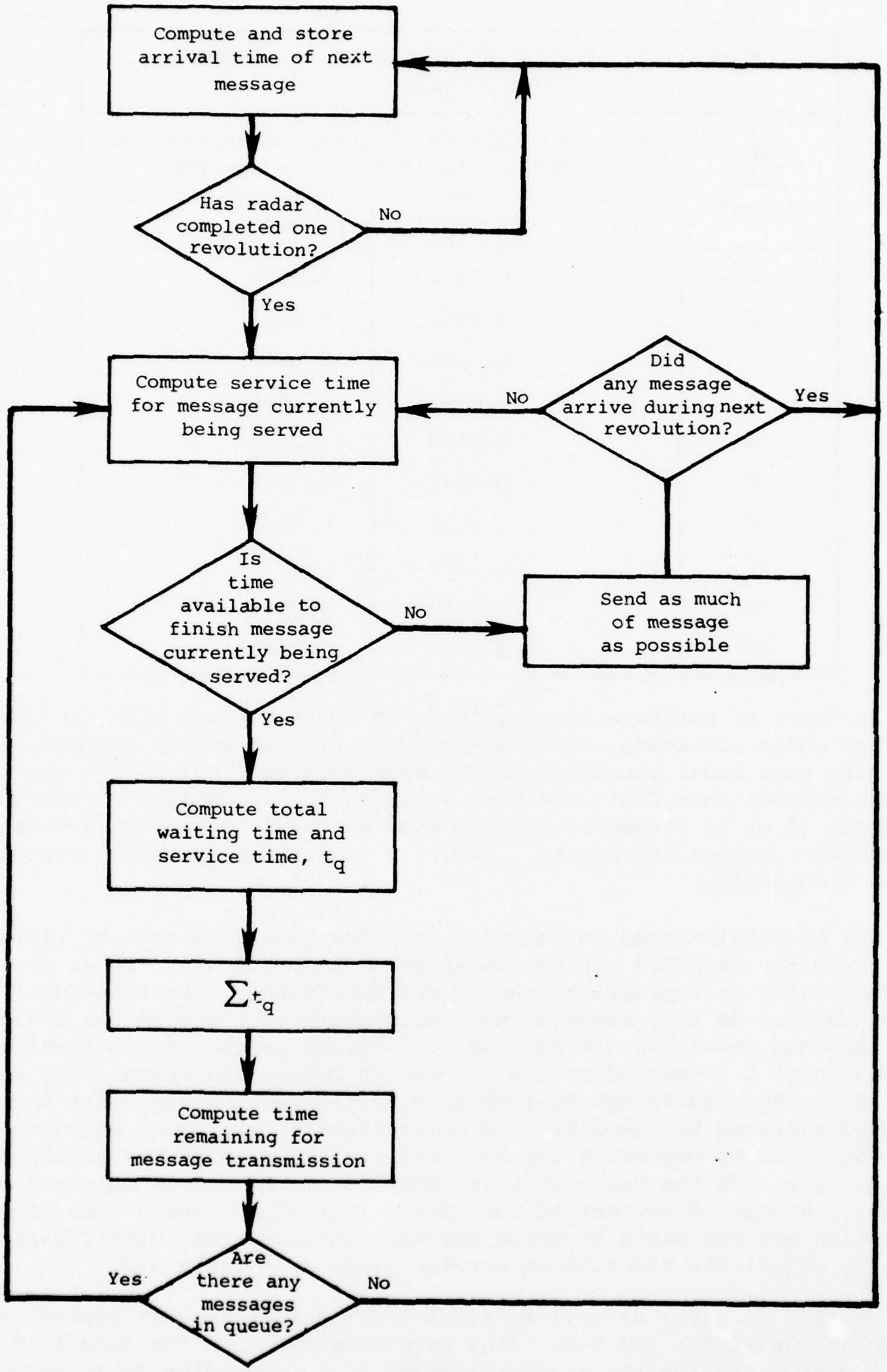

Figure 5-2. SIMULATION FLOW CHART

Number of Aircraft	Implementation Phase	Message Arrival Rate, $E(n)$ (Messages/ Second)	Mean Service Time, $E(t_s)$ (Seconds)	Standard Deviation, $S(t_s)$ (Seconds)
1	I	0.000280	0.003591	0.00007
	II	0.000737	0.009879	0.00752
	III	0.026292	0.004776	0.00377
2	I	0.000056	0.003591	0.00007
	II	0.001474	0.011451	0.00699
	III	0.052584	0.004813	0.00380
3	I	0.000084	0.003591	0.00007
	II	0.002211	0.011139	0.00704
	III	0.078876	0.004812	0.00380
4	I	0.000112	0.003591	0.00007
	II	0.002948	0.011139	0.00704
	III	0.105168	0.004812	0.00380
6	I	0.000168	0.003591	0.00007
	II	0.004422	0.013522	0.00537
	III	0.157752	0.006432	0.00462
8	I	0.000224	0.011421	0.00000
	II	0.005896	0.014224	0.00571
	III	0.210336	0.006469	0.00469
10	I	0.000280	0.011421	0.00000
	II	0.007370	0.008255	0.00477
	III	0.262920	0.008255	0.00000
12	I	0.000336	0.011421	0.00000
	II	0.008844	0.015666	0.00474
	III	0.315504	0.012269	0.00161
15	I	0.000420	0.013183	0.00007
	II	0.011055	0.016539	0.00502
	III	0.394380	0.012970	0.00201

Table 5-5. MEAN SERVICE TIMES FOR EN ROUTE COMMUNICATIONS

Table 5-6. MEAN SERVICE TIMES FOR TERMINAL COMMUNICATIONS				
Number of Aircraft	Implementation Phase	Message Arrival Rate, E(n) (Messages/ Second)	Mean Service Time, $E(t_S)$ (Seconds)	Standard Deviation, $S(t_S)$ (Seconds)
1	I	0.002084	0.002340	0.00024
	II	0.002084	0.002340	0.00024
	III	0.004584	0.002743	0.00040
2	I	0.004168	0.001846	0.00242
	II	0.004168	0.001846	0.00242
	III	0.009168	0.002249	0.00040
3	I	0.006252	0.001673	0.00024
	II	0.006252	0.001673	0.00024
	III	0.013752	0.002076	0.00040
4	I	0.008336	0.001599	0.00024
	II	0.008336	0.001599	0.00024
	III	0.018336	0.002002	0.00040
6	I	0.012504	0.001525	0.00024
	II	0.012504	0.001525	0.00024
	III	0.027504	0.001928	0.00040
8	I	0.016672	0.001476	0.00024
	II	0.016672	0.001476	0.00024
	III	0.036672	0.001879	0.00188
10	I	0.020840	0.001451	0.00024
	II	0.020840	0.001451	0.00024
	III	0.045840	0.001854	0.00040
12	I	0.025008	0.001426	0.00024
	II	0.025008	0.001426	0.00024
	III	0.055008	0.001829	0.00040
15	I	0.031260	0.001426	0.00024
	II	0.031260	0.001426	0.00024
	III	0.068760	0.001829	0.00040

of the cases considered was assumed to be constant. This simplified the simulation and had a negligible effect on the computed waiting time.

Another simplification in the analysis was realized by combining the uplink and downlink traffic. In actual operation, DABS uplink ELMs are supposed to take precedence over downlink ELMs. This has the effect of increasing the waiting time for downlink ELMs while reducing the waiting time for uplink transmissions. The average waiting time for all transactions, however, is independent of the queuing discipline. Since priority categories are not stipulated by the airlines, a single priority queue could in fact be established for both uplink and downlink company communications to minimize waiting times for downlink ELMs.

5.2 DABS TERMINAL CAPACITY

The queuing model described in Subsection 5.1.3 was used to evaluate DABS under the two extremes projected for the airline industry: (1) Phase I, immediate implementation with 1 aircraft; and (2) Phase III, possible future implementation with 15 aircraft. The results of these simulations, tabulated in Table 5-7, indicate that any given message would be delayed an average of two seconds for all scenarios considered in this study. Two seconds is the expected delay resulting from the random arrival of messages during a 4-second scan. Thus it is seen that no significant queuing occurs even under the "worst case" scenario postulated. This is not surprising in view of the low utilization of the communications link.

It is of considerable interest to know at what point traffic would begin to back up and how fast the system would deteriorate under added traffic. The results of additional simulations investigating this question are also shown in Table 5-7. The queuing model shows that appreciable delays begin to occur with a utilization of 0.13 and that catastrophic deterioration begins around 25 percent utilization. This latter phenomenon illustrates the importance of accurate traffic forecasts in predicting system behavior.

It is unusual to observe such a rapid buildup in traffic at utilization levels of only 25 percent. The explanation lies in the fact that the message arrival rate used in the simulation is measured in messages per second. The true arrival rate is, in effect, four times greater than this because of the accumulation of messages during the 4-second period during which the aircraft is out of the radar beam. The actual utilization of the DABS link corresponding to the worst case in Table 5-7 is correctly given by the following expression:

$$\frac{(0.025 \text{ sec/msg})\ (0.287 \text{ msg/sec})\ (4 \text{ sec/scan})}{(0.031 \text{ second per scan})}$$

or nearly 93 percent. At 100 percent utilization, messages arrive just as quickly as they are transmitted and the queue is never dissipated. Under these conditions, the delays would approach infinity. Compared with the

Table 5-7. AVERAGE TRANSMISSION TIME FOR TERMINAL COMMUNICATIONS

Implementation Phase	Number of Aircraft	Message Arrival Rate (Messages/Second)	Service Time (Seconds)	Time Available (Seconds)	Utilization of Time Available	Total Messages Simulated	Actual Arrival Rate (Messages/Second)	Mean Time Waiting and Being Served (Seconds)
I	1	0.002	0.0023	0.037	0.0001	1045	0.002	2.04
III	15	0.069	0.0014	0.031	0.0031	1172	0.067	1.98
-	15	0.200	0.0200	0.031	0.1290	1576	0.192	3.91
-	15	0.300	0.0200	0.031	0.1935	1207	0.289	6.06
-	15	0.300	0.025	0.031	0.2419	1124	0.287	17.46

delay expected under the "worst case" scenario projected for Phase III, traffic could increase almost 75 times before waiting times of 17 or more seconds would be encountered. It is therefore reasonable to assume that terminal radar systems are easily capable of meeting foreseeable traffic demands in the vicinity of airports.

5.3 DABS EN ROUTE CAPACITY

The DABS en route capability analysis showed significant queuing under the "worst case" scenario with 15 aircraft. The expected delay under these conditions would be 11.8 seconds, whereas it would be 6 seconds under little- or no-load conditions. Six seconds in this case corresponds to the average waiting time with random arrivals and a 12-second scan.

Two sets of simulation runs were made in order to investigate the complex interplay of time available and service time under heavy traffic loads. The first group of runs maintained a constant message volume to each aircraft while the number of aircraft varied. The second group of runs caused the traffic load to vary but maintained the number of aircraft constant.

The results of these runs, tabulated in Table 5-8, show that delays encountered in Phase III start to increase rapidly once the actual system utilization reaches about 64 percent. The reason for this behavior is that the number of message arrivals per second is amplified by a factor of 12 because of the 12-second rotation of the radar. Any change in traffic load is, in effect, magnified nearly 12 times.

Table 5-8 also shows that the maximum load expected in Phase II could increase approximately tenfold before any noticeable increase in waiting time was detected. With Phase III traffic estimates, noticeable queues would start to build with 12 or more aircraft in any 4° sector.

The ability of DABS to handle en route company communications appears to be marginal at the maximum traffic levels predicted for possible future implementation in Phase III. No appreciable change in waiting time is expected under any of the Phase I or Phase II scenarios, however.

Table 5-8. AVERAGE DELAY FOR EN ROUTE COMMUNICATIONS

Implementation Phase	Number of Aircraft	Message Arrival Rate (Messages/Second)	Service Time (Seconds)	Time Available per Scan (Seconds)	Utilization of Time Available	Total Messages Simulated	Observed Arrival Rate (Messages/Second)	Mean Time Waiting and Being Served (Seconds)
I	1	0.00003	0.0036	0.090	0.0000+	1222	0.00003	5.87
II	15	0.011	0.0165	0.066	0.0028	1058	0.011	5.91
III	10	0.263	0.008	0.071	0.0296	1968	0.257	6.12
III	12	0.316	0.012	0.069	0.0549	1860	0.308	7.86
III	15	0.394	0.013	0.066	0.0776	3351	0.367	11.81
-	15	0.400	0.013	0.066	0.0788	1393	0.384	13.25
-	15	0.400	0.015	0.066	0.0910	617	0.358	22.60
-	15	0.100	0.013	0.066	0.0197	1800	0.097	6.00

CHAPTER SIX

COMPANY INTERFACE WITH DABS

A major consideration in adapting DABS to airline company communications is the complexity of the interfaces required at various points in the network. The contract effort therefore required the development of possible interface procedures between the FAA communications systems and the company communications systems. Since detailed procedures are dependent on the planned site distribution of DABS, currently undefined, this study has considered the general architecture required for an interface based on the existing company communications network. Figure 6-1 illustrates one method of interconnection to provide a data link between the airline company and its aircraft. While other arrangements are possible, the essential features are basically the same and similar interface problems will be encountered.

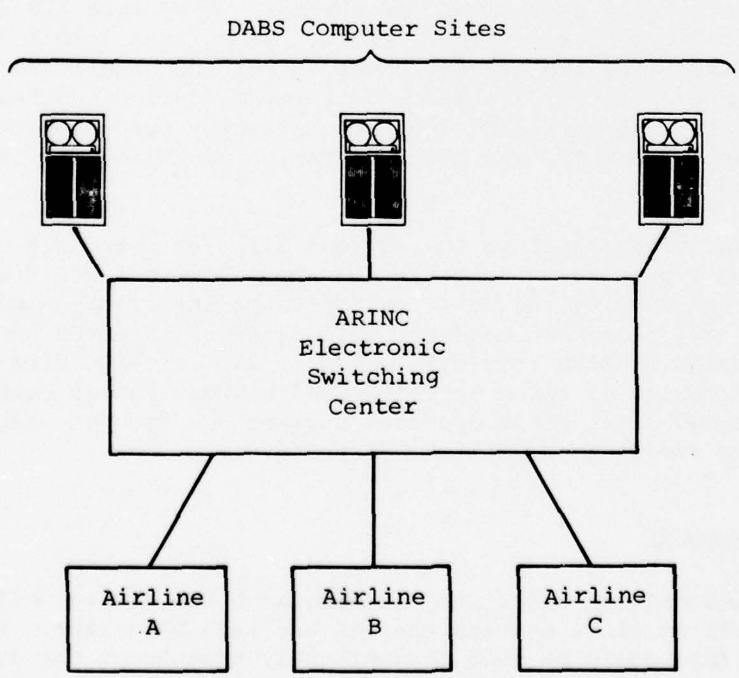

Figure 6-1. TYPICAL DABS/COMPANY COMMUNICATIONS INTERCONNECTION

The interfaces required for DABS are best understood by considering the flow of data through the system. An airline company with a message to send enters the data on a private data line between its office and an electronic switching system (ESS) center. The ESS center routes the message to the appropriate DABS computer site via a private line network. The DABS computer, in turn, relays the data to the aircraft. A message originated by the aircraft follows the reverse route. The four major subsystems involved in this process are:

- Data Terminals
- Ground Network
- Electronic Switching Center
- DABS Computer Sites

These subsystems are described in the following paragraphs.

6.1 DATA TERMINAL

From the descriptions of the various message types in Chapter Three, it is apparent that a variety of terminal equipments is required to perform such functions as engine monitoring, reservations confirmation, and flight following. Engine and airframe monitoring, for example, require special sensing devices and encoding logic to generate an appropriately formatted message. Somewhat different arrangements, however, are demanded by flight reports requiring crew attention. Examples are departure and arrival times, which can be entered and transmitted in a fixed format and sequence. Such stylized messages are generally very brief and usually consist of a stream of numbers. A third category of terminal devices contains provisions for free-text entry and requires hard-copy output. These terminals would have full keyboards, and their operation would require the attention of a crew member.

The ground counterpart to the various airborne terminals would, in most cases, be a computer. Suitable programs, however, would be required to interpret and display the data, and operator intervention would be necessary for all free-text messages originated or received on the ground. The nominal speed of DABS terminals would be 2400 or 4800 bits per second. The major limitation on speed is the ground network design rather than the air-to-ground link, which operates between one and four megabits per second for the downlink and uplink, respectively.

6.2 GROUND NETWORK

The ground network comprises links between the airline offices and the ESS as well as links between the ESS and each DABS site. Leased voice-grade lines would be used predominantly throughout the system. Most airlines currently lease data circuits between their various offices and

the ARINC ESS. Much of the forecast traffic load could therefore be transmitted over existing facilities, although additional circuits would undoubtedly be required in some cases. The part of the network connecting the ESS to each DABS site could be provided by ARINC, on a not-for-profit basis, over private voice grade lines.

6.3 ELECTRONIC SWITCHING SYSTEM CENTER

The ESS can easily accommodate the DABS company communications concept. It serves the practical purpose of concentrating lines and circuits to minimize the total number of connections required at each DABS site. Airlines are spared the cost of having an individual line to each site, and the DABS computers are not confronted with the problem of interfacing a large number of airline circuits. This type of concentration is based on the application of queuing theory with random message arrivals. Although the total number of messages may be quite large, the instantaneous traffic load may be predictably handled with a moderate number of lines.

The problem of locating a specific aircraft can be resolved in several ways. Perhaps the simplest way is to use an interactive dialogue between the DABS sites and the ESS. A file of aircraft identification (ID) numbers is maintained in the ESS. The DABS site responsible for each aircraft is also listed in this file. Whenever an aircraft is handed off to another site, the new site transmits the aircraft ID to the ESS, where the file is updated. Each aircraft ID is activated by the pilot with an appropriately addressed message to the ESS when the flight originates. The pilot must also deactivate his ID upon arrival at his destination. Messages for any ID that is inactive are not accepted by the ESS.

A back-up approach for use in unusual circumstances requires the ground to input the origin, destination, ETA, and departure time. An algorithm is used to bracket the possible DABS sites involved. These sites are queried in turn to establish which has control of the flight. The message is then transmitted to the appropriate site to be relayed to the aircraft.

Messages originated by in-flight aircraft are accommodated without modification to the ESS. Each message contains the appropriate office address and is routed directly through the DABS computer and the existing ESS network to the correct office or offices.

6.4 DABS COMPUTER

In addition to its surveillance functions, the DABS computer must be programmed to pass aircraft ID numbers to the ARINC ESS. Communications capabilities for receiving and transmitting messages must also be implemented through either additional software or a front-end communications processor. In either case, buffer storage must be used to hold the

complete message until it can be transmitted to the aircraft or until a transmission from the aircraft is complete. This store and forward capability is required because of the difference in speed between the ground network and the radio link. Buffering is also required to assure message integrity in the event of uplink or downlink transmission errors.

CHAPTER SEVEN

DISCUSSION OF RESULTS

Several traffic scenarios were postulated for the DABS communications link on the basis of data obtained from the airline industry. These scenarios comprised three implementation levels ranging from immediate airline requirements to possible future requirements. These scenarios also distinguished between en route and terminal traffic because of fundamental differences in the characteristics of the radars employed. For the purposes of this study, it was assumed that the rotation period of an en route radar is 12 seconds while that of a terminal radar is only 4 seconds. Radar beamwidth was nominally 4°, and a constant pulse repetition frequency of 100 pulses per second was assumed throughout.

The density of aircraft in any 4° sector was permitted to vary from 1 to 15. For the en route analysis, these aircraft were uniformly distributed over a 200-mile corridor, with a mean range of 100 miles to the radar facility. The terminal analyses, however, assumed a separation between aircraft that decreased as they approached the radar facility. No distinction was made between uplink and downlink communications priorities since none had been specified by the airlines in their traffic data. All aircraft were assumed to be DABS-equipped certified air carriers.

The most important measurement of DABS capacity, and the one used in this study, is the expected delay when a message enters the system. The delay in this case is the total time the message spends waiting and being transmitted. Three variables were required to estimate the mean delay: the time available for company communications in each radar scan, the mean service time per message, and the mean arrival rate of messages. All of these factors are dependent on the number of aircraft in the radar beam. Figures 7-1 through 7-3 show how each of these factors varied with the number of aircraft under the stated assumptions. As shown in Figure 7-1, the message arrival rate is directly proportional to the number of aircraft in a given 4° sector. Figure 7-2 shows service times increasing rapidly for en route communications as the number of aircraft increase. Terminal communications service times, however, remain essentially unchanged over a broad range of aircraft because of the decrease in average range as more aircraft enter the terminal area. Figure 7-3 reflects the steady decrease in available time as the number of en route aircraft increases, while the time available in terminal areas is essentially constant. In the latter case, this behavior is due to the decreasing

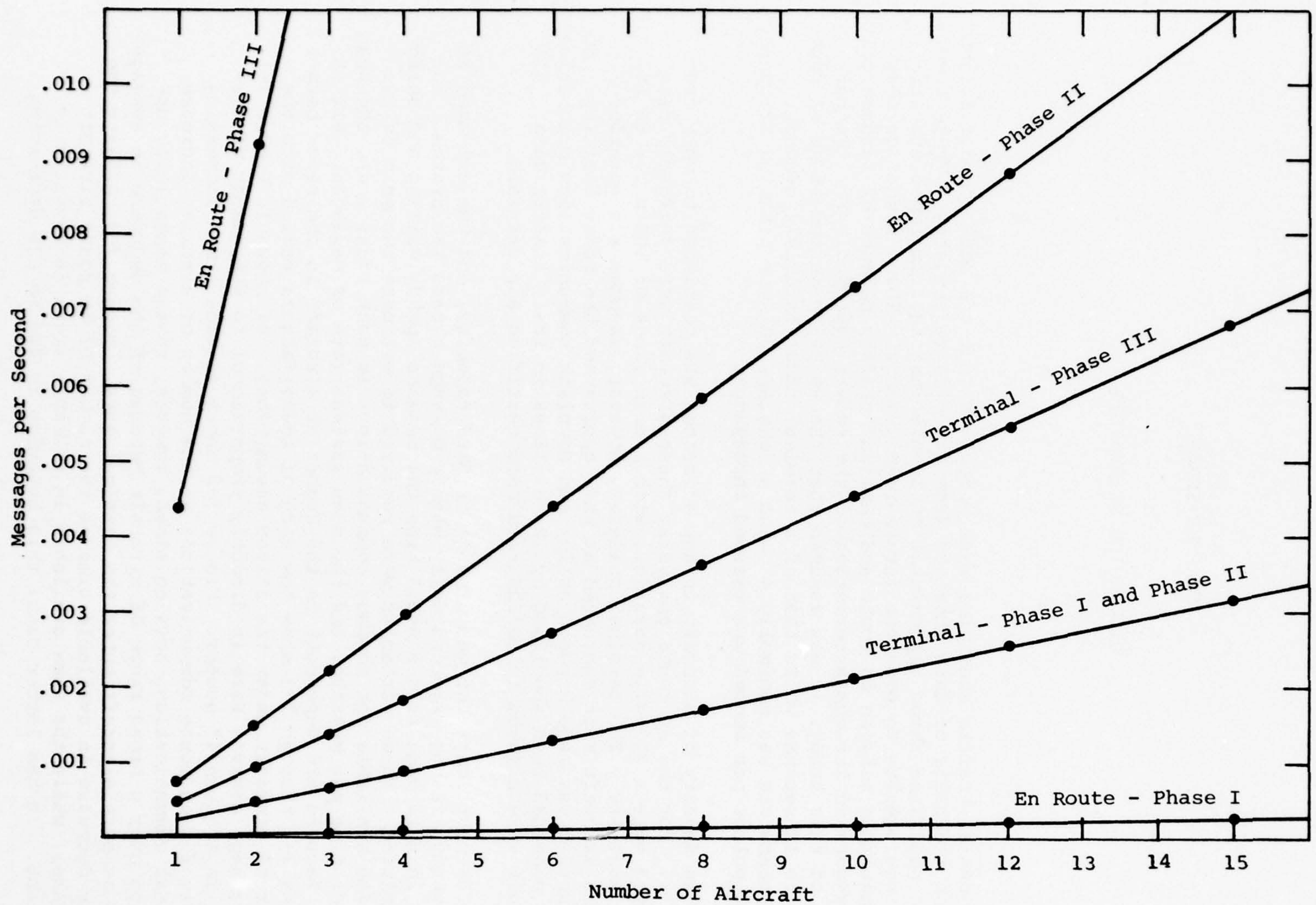

Figure 7-1. MESSAGE ARRIVAL RATE AT VARIOUS LEVELS OF IMPLEMENTATION

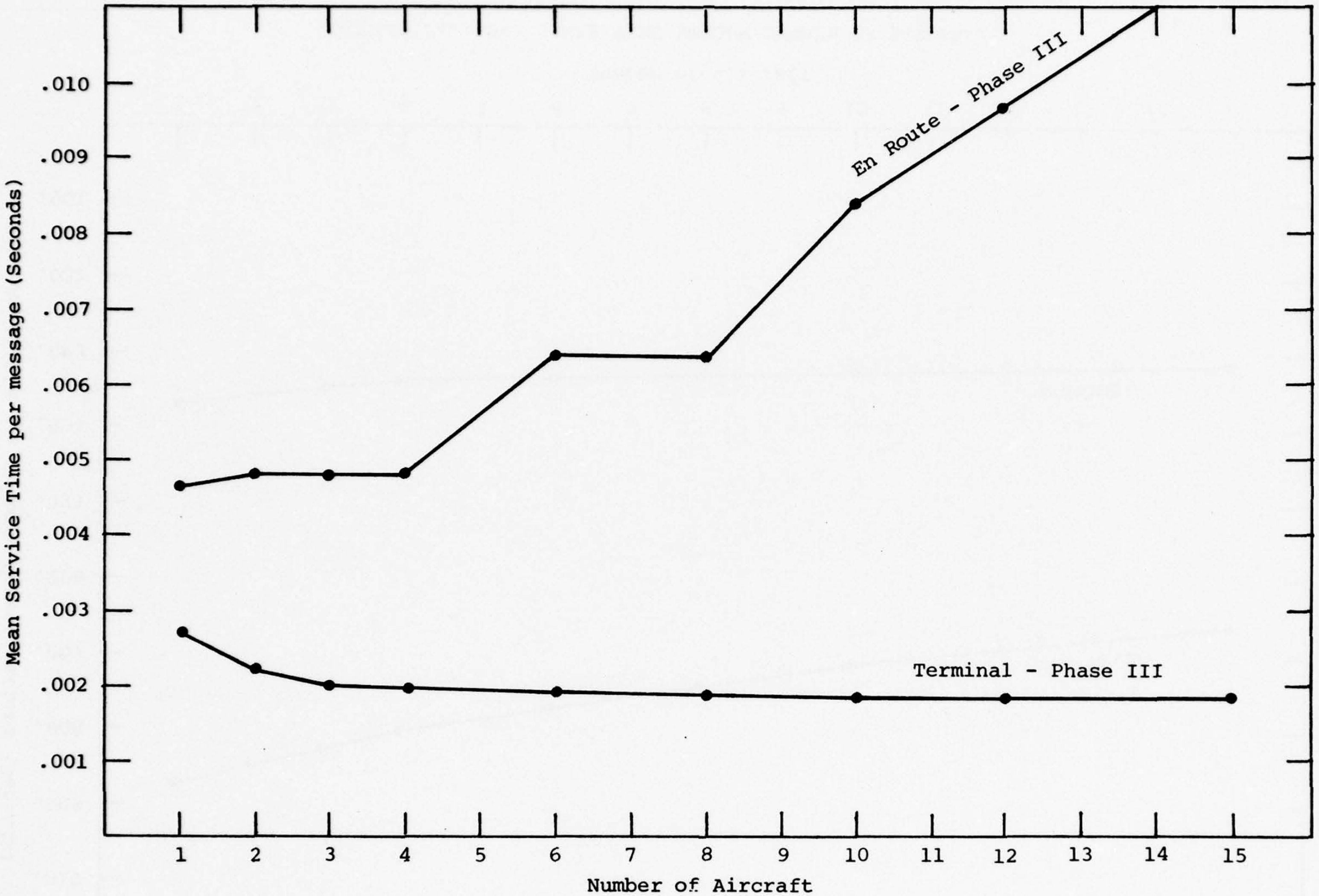

Figure 7-2. MEAN SERVICE TIME FOR A MESSAGE

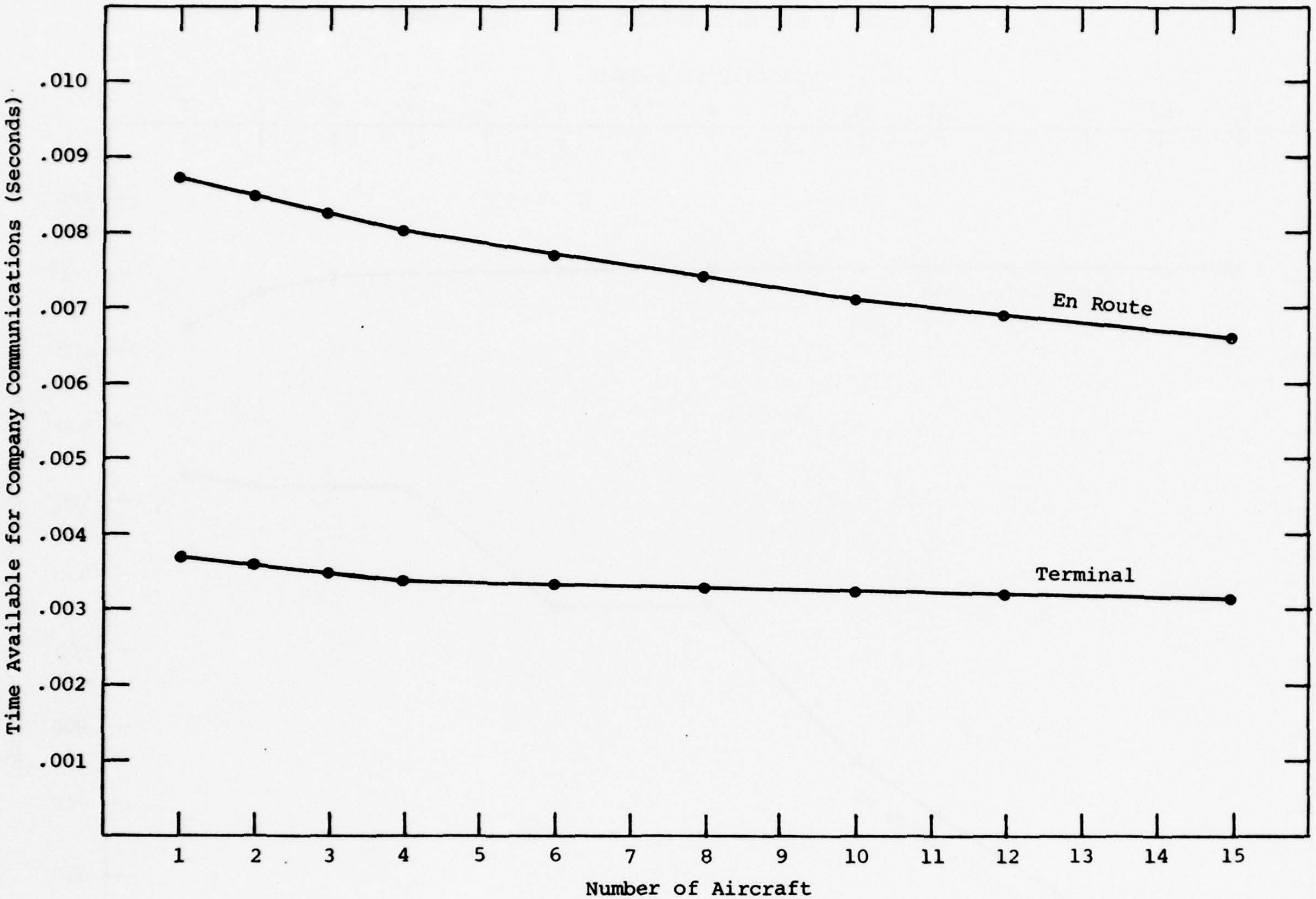

Figure 7-3. AVAILABLE TIME VERSUS NUMBER OF AIRCRAFT

separation of aircraft as they approach the airport and a corresponding decrease in average range as the number of aircraft increases.

The expected delays for several scenarios are illustrated in Figure 7-4. While no delays were evident in the terminal system for any level of projected traffic, significant queue buildup and delays can be expected on the en route system with 15 or more aircraft and possible future traffic loads. No significant queues will develop on the en route system, however, with less message traffic or fewer aircraft.

Another measure of traffic load is the product of arrival rate, mean service time, and number of aircraft. If delays are plotted against this product while the number of aircraft is held constant at 15, the curves shown in Figure 7-5 are obtained. In order to show both terminal delays and en route delays near their critical points, terminal traffic estimates from 10 to 100 times greater than those forecast for possible future implementation were assumed. Thus few delays, if any, could be expected in company communications transmitted through terminal radars under the worst of foreseeable circumstances. Under the worst-case scenario projected for en route communications, however, the system is nearing saturation. A relatively small increase in the number of aircraft or messages would result in large queues and long waiting times.

Most company communications are generated by certified air carriers. The actual traffic load would therefore depend mainly on the total number of certified air carriers in the radar beam at a given instant. It appears that less than two-thirds of the aircraft would fall into this category, on the basis of the ratio of certified carriers to other types of aircraft. The en route delays projected in the worst-case scenarios therefore correspond to 22 or 23 aircraft within a given 4° sector. Even if aircraft traffic were to reach these levels, communications delays would not be encountered unless a number of doubtful future service innovations in Phase III were implemented by the air carriers.

One factor beyond the scope of this study that would have an adverse affect on DABS capacity is the communications error rate. The primary effect of errors due to noise and transponder replies from aircraft beyond the assumed radar coverage area is to increase the number of ELMs transmitted. Each error may cause one or more ELMs to be repeated, which effectively increases the total number of messages waiting and the expected delay.

Another factor that would influence delay times is the assignment of different priorities to uplink and downlink company communications. While the average waiting times for all messages would remain unchanged, the lower-priority messages would experience delays several times longer than the average. This would become particularly bothersome with the en route system under the loads projected for possible future implementation.

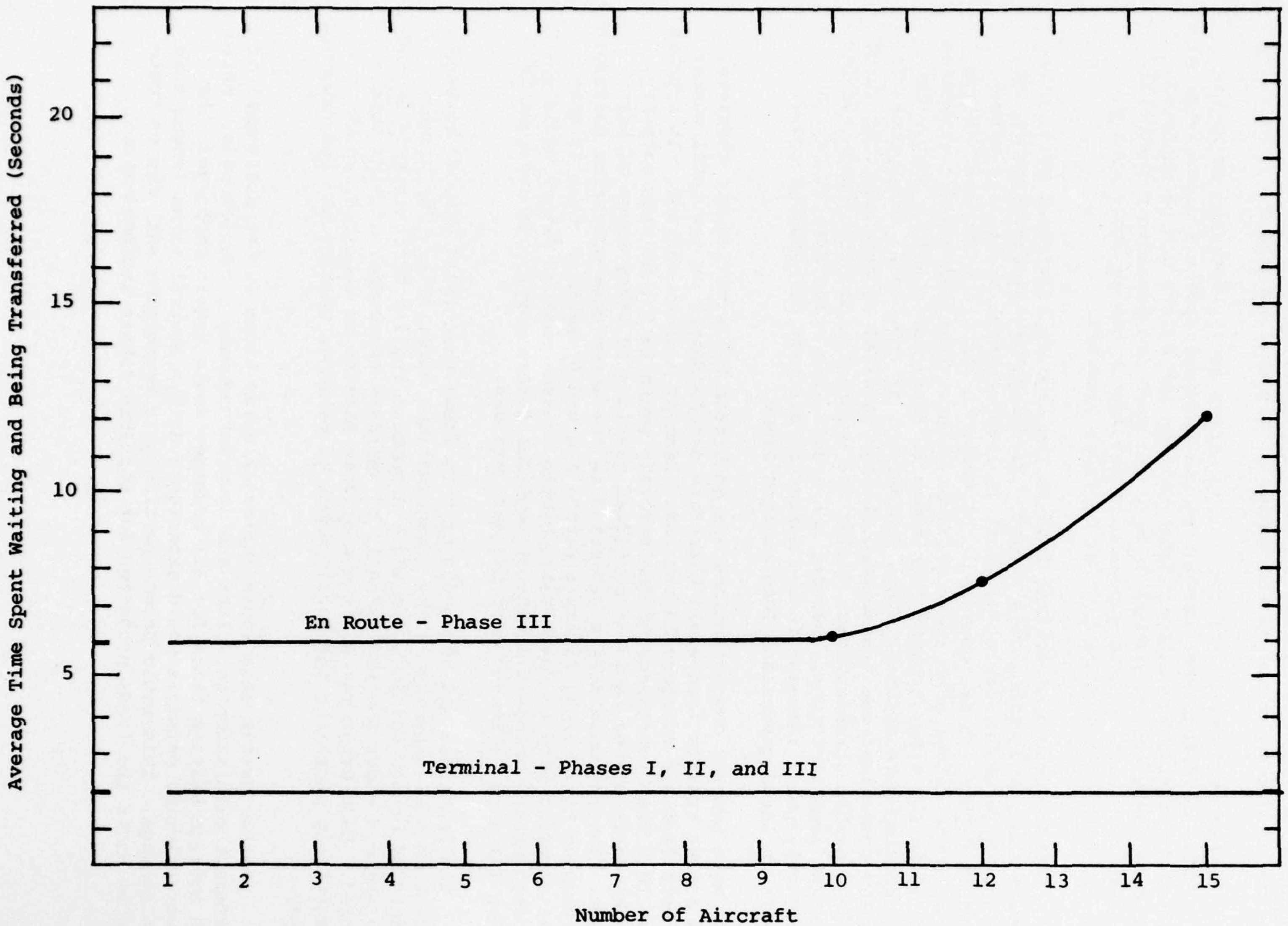

Figure 7-4. EXPECTED DELAY VERSUS NUMBER OF AIRCRAFT

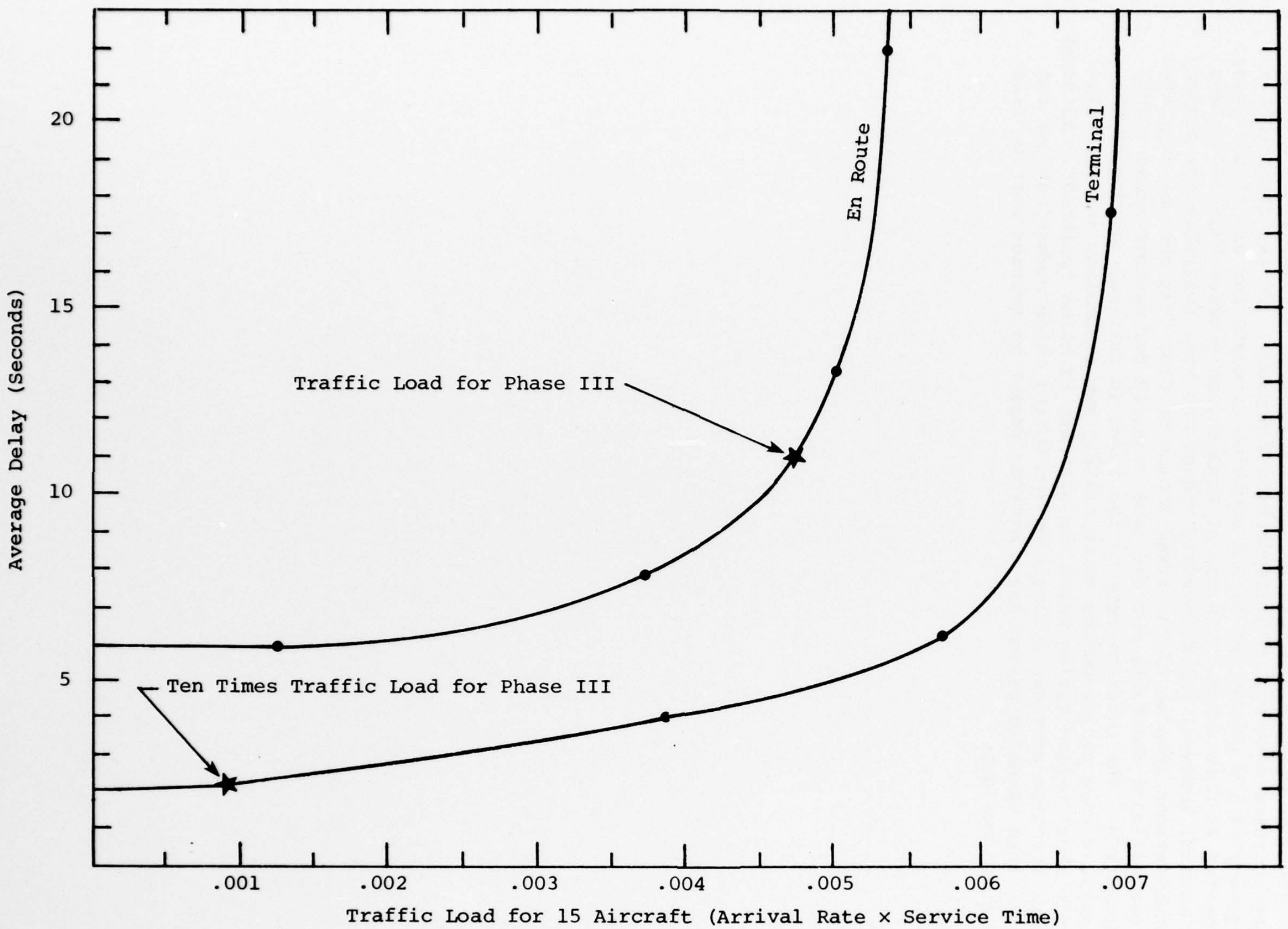

Figure 7-5. DELAY AS A FUNCTION OF TRAFFIC LOAD

The most critical factors influencing message waiting times are the radar rotation rate and pulse repetition frequency. It was found that a frequency of 100 pulses per second would be adequate for all of the loads projected in this study. The use of frequencies greater than 100 pulses per second, however, would severely reduce the time available for company communications because of the fixed amount of time that must be dedicated to surveillance functions and the time required for maximum-range signal propagation. The rotation rate of the radar is critical because of the relatively long period during which traffic may accumulate and the relatively short period during which the aircraft is being "painted". Although slower rotation provides a longer period during which communications can occur, this extended period has a greater impact on average waiting time and queue buildup.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

This study has reviewed the present and proposed company communications required in support of air carrier operations to provide efficient scheduling of equipment and crews and to promote passenger services. The communications were categorized according to frequency, phase of flight, and possible message length to establish the expected demand on any data link dedicated to support the exchange of information between ground operations and an aircraft in flight.

The data link capability of DABS was investigated as a possible medium for the transfer of company communications. Scheduling and simulation models were developed to categorize the surveillance characteristics of DABS and evaluate the available time for communications during the portion of a radar scan where an aircraft is visible to DABS. In the assumptions concerning the availability of the DABS data link for company communications, all nonsurveillance times were allocated to this service. Aircraft densities evaluated ranged from 1 aircraft in the 4° beam to a maximum of 15, which would be representative of an approach corridor in terminal areas or dense traffic corridors in en route areas.

The analysis of the ability of DABS to handle the company communications of the air carrier industry was segmented into three phases of possible implementation (immediate, future, and possible future) and two areas of operation (terminal and en route). For the situations considered by this study, analysis yields the following conclusions:

- Terminal radars have the capacity to handle all implementation levels of company communications without creating excessive message delays.
- En route radars have the capacity to handle the immediate and future company communications even in dense traffic environments without excessive message delays.
- En route radars are susceptible to excessive delays and buildup of communications backlog when possible future company communications are implemented.
- En route radars would probably saturate their communications capacity if either the traffic density or communication message lengths were to increase beyond the levels projected in this study.

The evaluation of the DABS data link has been limited to company communications, with the assumptions that all transmissions would be error-free and that only routine surveillance functions would be transacted by DABS. The introduction of separation assurance, ATC record communications, and varying levels of ATC automation will greatly affect the available communications time of the DABS data link. Proposed implementation of any service on the DABS data link must include an in-depth analysis of all planned or possible uses of the DABS to ensure long-term system availability as a communication medium in light of the potential saturation of en route systems under the possible scenarios developed in this study.

APPENDIX

DABS MODELS

This appendix presents the various DABS models developed for the study, together with the programs applicable to the Hewlett-Packard HP 67/97 calculators. These calculators were ideally suited to the effort because of the necessity for fast programming and debugging capability, the ease with which subroutines could be modified and transferred between programs, and the overall convenience of a portable, card programmable calculator.

1. DABS SURVEILLANCE MODEL

The DABS Surveillance Model accepts the ranges of up to 19 aircraft and computes the time required in each cycle for scheduling. It is assumed that all aircraft are in the radar beam simultaneously and that a PRF of 100 is used.

User instructions are as follows:

1. Enter DABS Surveillance Program.
2. Initialize program by depressing "A".
3. Enter the ranges (in descending order) for all aircraft. After each entry press "B". Information displayed is range in nautical miles.
4. Press "C" to run program.
5. Display will show the total time in seconds required for both ATCRBS and DABS surveillance interrogations.

DABS Scheduling

001	*LBLA	21 11
002	ENG	-13
003	DSP2	-63 02
004	0	00
005	STOI	35 46
006	*LBL0	21 00
007	RCLI	36 46
008	EEX	-23
009	+	-55
010	STOI	35 46
011	RTN	24
012	*LBLB	21 12
013	STOi	35 45
014	RCLI	36 46
015	STOE	35 15
016	1	01
017	9	09
018	X=Y?	16-33
019	GTO8	22 08
020	GTO0	22 00
021	*LBL8	21 08
022	GTO9	22 09
023	*LBLC	21 13
024	RCLE	36 15
025	CHS	-22
026	X>0?	16-44
027	GTO8	22 08
028	X=0?	16-43
029	GTO9	22 09
030	DSP3	-63 03
031	ENG	-13
032	1	01
033	STOI	35 46
034	0	00
035	STOA	35 11
036	*LBLc	21 16 13
037	SF1	16 21 01
038	RCLi	36 45
039	ENT↑	-21
040	+	-55
041	6	06
042	.	-62
043	1	01
044	7	07
045	8	08
046	EEX	-23
047	6	06
048	CHS	-22
049	×	-35
050	3	03
051	5	05
052	EEX	-23
053	6	06
054	CHS	-22
055	+	-55
056	STOB	35 12
057	F1?	16 23 01
058	STO0	35 00
059	CF1	16 22 01
060	EEX	-23
061	STOD	35 14
062	RCLI	36 46
063	FIX	-11
064	ENG	-13
065	*LBLa	21 16 11
066	RCLI	36 46
067	RCLE	36 15
068	X=Y?	16-33
069	GTOb	22 16 12
070	RCLi	36 45
071	RCLI	36 46
072	EEX	-23
073	+	-55
074	STOI	35 46
075	R↓	-31
076	RCLi	36 45
077	-	-45
078	ENT↑	-21
079	+	-55
080	6	06
081	.	-62
082	1	01
083	7	07
084	8	08
085	EEX	-23
086	6	06
087	CHS	-22
088	×	-35
089	1	01
090	1	01
091	7	07
092	EEX	-23
093	6	06
094	CHS	-22
095	+	-55
096	STOC	35 13
097	RCLB	36 12
098	X⇄Y	-41
099	-	-45
100	STOB	35 12
101	X<0?	16-45
102	GTOb	22 16 12
103	RCLI	36 46
104	FIX	-11
105	ENG	-13
106	RCLD	36 14
107	EEX	-23
108	+	-55
109	STOD	35 14
110	GTOa	22 16 11
111	*LBLb	21 16 12
112	RCL0	36 00
113	2	02
114	8	08
115	EEX	-23
116	6	06
117	CHS	-22
118	+	-55
119	RCLD	36 14
120	1	01
121	1	01
122	7	07
123	EEX	-23
124	6	06
125	CHS	-22
126	×	-35
127	+	-55
128	5	05
129	EEX	-23
130	6	06
131	CHS	-22
132	-	-45
133	DSP3	-63 03
134	RCLA	36 11
135	+	-55
136	STOA	35 11
137	RCLI	36 46
138	RCLE	36 15
139	X≠Y?	16-32
140	GTOc	22 16 13
141	RCLB	36 12
142	X<0?	16-45
143	GTOc	22 16 13
144	RCLA	36 11
145	FIX	-11
146	DSP6	-63 06
147	R/S	51

2. DABS UPLINK ELM MODEL

The DABS Uplink ELM Model computes the total time required to transmit a message of given length. Inputs are the time available during an interrogation cycle that includes an ATCRBS and DABS interrogation, the time available during a cycle that includes an ATCRBS but not a DABS interrogation, the number of times each aircraft is painted during one revolution, the length of the message, and the range to each aircraft in the order in which messages are to be sent.

User instructions are as follows:

1. Enter DABS Uplink ELM Program.
2. Press "A" to initialize program.
3. Enter the time in seconds available for company communications in a cycle that includes both ATCRBS and DABS interrogations.
4. Press "f" and then "A".
5. Enter the time in seconds available for company communications in a cycle that includes only an ATCRBS interrogation.
6. Press "f" and then "B".
7. Enter the number of times an aircraft is "painted" by the radar during one revolution.
8. Press "f" and then "C".
9. Enter the number of ELMs to be transmitted. (No more than 99 ELMs are permitted.)
10. Press "f" and then "D".
11. Enter the range in nautical miles to the aircraft with the first message, and press "B".
12. Repeat step 7 for each aircraft with a message. (No more than 15 aircraft are permitted.)
13. Press "C" to run program.
14. Output is the total elapsed time in seconds from the moment the first aircraft is "painted" to the moment the last aircraft with a message acknowledges message receipt.

DABS Uplink ELM

001	*LBLC	21 13
002	DSP0	-63 00
003	SF2	16 21 02
004	1	01
005	STO1	35 01
006	4	04
007	STOI	35 46
008	RCLA	36 11
009	STO4	35 04
010	*LBL1	21 01
011	RCLE	36 15
012	RCLI	36 46
013	1	01
014	+	-55
015	STOI	35 46
016	4	04
017	-	-45
018	PSE	16 51
019	X>Y?	16-34
020	GTO9	22 09
021	RCLD	36 14
022	STO0	35 00
023	*LBL2	21 02
024	CF0	16 22 00
025	1	01
026	6	06
027	RCL0	36 00
028	X≤Y?	16-35
029	SF0	16 21 00
030	X>Y?	16-34
031	X⇄Y	-41
032	STO2	35 02
033	RCL4	36 04
034	5	05
035	0	00
036	GSBe	23 16 15
037	÷	-24
038	INT	16 34
039	STO3	35 03
040	X>Y?	16-34
041	GTO8	22 08
042	X=Y?	16-33
043	GTO8	22 08
044	RCL3	36 03
045	5	05
046	0	00
047	GSBe	23 16 15
048	×	-35
049	ST-4	35-45 04
050	RCL3	36 03
051	ST-0	35-45 00
052	GSB0	23 00
053	GSB4	23 04
054	GTO2	22 02
055	*LBL8	21 08
056	RCL2	36 02
057	5	05
058	0	00
059	GSBe	23 16 15
060	×	-35
061	ST-4	35-45 04
062	GSB0	23 00
063	F0?	16 23 00
064	GTO3	22 03
065	1	01
066	6	06
067	ST-0	35-45 00
068	*LBL3	21 03
069	CF1	16 22 01
070	GSB7	23 07
071	RCL4	36 04
072	X<0?	16-45
073	SF1	16 21 01
074	X<0?	16-45
075	GSB4	23 04
076	F1?	16 23 01
077	GSB7	23 07
078	F1?	16 23 01
079	GSB6	23 06
080	CF1	16 22 01
081	GSB7	23 07
082	GSB6	23 06
083	RCL4	36 04
084	X<0?	16-45
085	SF1	16 21 01
086	X<0?	16-45
087	GSB4	23 04
088	F1?	16 23 01
089	GSB7	23 07
090	F1?	16 23 01
091	GSB6	23 06
092	F0?	16 23 00
093	GTO1	22 01
094	GTO2	22 02
095	*LBL9	21 09
096	RCL1	36 01
097	1	01
098	-	-45
099	RCLC	36 13
100	÷	-24
101	STOI	35 46
102	INT	16 34
103	4	04
104	×	-35
105	RCLI	36 46
106	FRC	16 44
107	RCLC	36 13
108	×	-35
109	EEX	-23
110	2	02
111	CHS	-22
112	×	-35

DABS Uplink ELM

113	+	-55
114	STOI	35 46
115	RCLA	36 11
116	RCLB	36 12
117	F2?	16 23 02
118	X≷Y	-41
119	RCL4	36 04
120	-	-45
121	RCLI	36 46
122	+	-55
123	FIX	-11
124	DSP6	-63 06
125	RTN	24
126	*LBL5	21 05
127	1	01
128	2	02
129	.	-62
130	3	03
131	5	05
132	4	04
133	*LBLe	21 16 15
134	EEX	-23
135	6	06
136	÷	-24
137	RTN	24
138	*LBL0	21 00
139	RTN	24
140	*LBLA	21 11
141	5	05
142	STOI	35 46
143	0	00
144	STOE	35 15
145	1	01
146	RTN	24
147	*LBLB	21 12
148	STOi	35 45
149	RCLI	36 46
150	1	01
151	+	-55
152	STOI	35 46
153	RCLE	36 15
154	1	01
155	+	-55
156	STOE	35 15
157	1	01
158	+	-55
159	RTN	24
160	*LBL4	21 04
161	CF2	16 22 02
162	1	01
163	ST+1	35-55 01
164	RCLB	36 12
165	STO4	35 04
166	RCL1	36 01
167	1	01
168	-	-45
169	RCLC	36 13
170	÷	-24
171	DSP4	-63 04
172	RND	16 24
173	FRC	16 44
174	X≠0?	16-42
175	RTN	24
176	RCLA	36 11
177	STO4	35 04
178	SF2	16 21 02
179	RTN	24
180	*LBL7	21 07
181	GSB5	23 05
182	RCLi	36 45
183	×	-35
184	1	01
185	5	05
186	5	05
187	GSBe	23 16 15
188	+	-55
189	ST-4	35-45 04
190	RTN	24
191	*LBL6	21 06
192	3	03
193	1	01
194	GSBe	23 16 15
195	ST-4	35-45 04
196	RTN	24
197	*LBLa	21 16 11
198	STOA	35 11
199	RTN	24
200	*LBLb	21 16 12
201	STOB	35 12
202	RTN	24
203	*LBLc	21 16 13
204	STOC	35 13
205	RTN	24
206	*LBLd	21 16 14
207	STOD	35 14
208	RTN	24
209	R/S	51

3. DABS DOWNLINK ELM MODEL

The DABS Downlink ELM Model computes the total time required to transmit a message of given length to one or more aircraft. Program inputs are time available for company communications when ATCRBS and DABS interrogations are both included in a cycle, the time available for company communications when only ATCRBS interrogations are included, the number of times each aircraft is "painted" during each scan, and the range to each aircraft with a message.

User instructions are as follows:

1. Enter DABS Downlink ELM Program.
2. Press "A" to initialize program.
3. Enter the time in seconds available for company communications during a cycle that includes both ATCRBS and DABS interrogations. Press "STO" and then "A".
4. Enter the time in seconds available for company communications during a cycle that includes only ATCRBS interrogations. Press "STO" and then "B".
5. Enter the number of times each aircraft is "painted" during one revolution. Press "STO" and then "C".
6. Enter the number of ELMs per message (must be less than 99). Press "STO" and then "D".
7. Enter the range to the aircraft with the first message and press "B".
8. Repeat step 7 for each aircraft. (No more than 15 aircraft are permitted.)
9. Press "C" to run program.
10. Output is the total elapsed time in seconds from the moment the first aircraft is "painted" to the moment the last aircraft with a message transmits its "clear buffer" pulse.

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DABS Downlink ELM

```
001  *LBLC      21 13
002    SF2   16 21 02
003      1         01
004   STO1      35 01
005      4         04
006   STOI      35 46
007   RCLA      36 11
008   STO4      35 04
009  *LBL1      21 01
010   RCLE      36 15
011   RCLI      36 45
012      1         01
013      +        -55
014   STOI      35 46
015      4         04
016      -        -45
017    PSE      16 51
018   X>Y?      16-34
019   GTO9      22 09
020   RCLD      36 14
021   STO0      35 00
022  *LBL2      21 02
023    CF0   16 22 00
024    CF1   16 22 01
025   RCLi      36 45
026   GSBd   23 16 14
027      ×        -35
028      5         05
029      0         00
030   GSBe   23 16 15
031      +        -55
032   ST-4   35-45 04
033   RCL4      36 04
034      1         01
035      3         03
036      6         06
037   GSBe   23 16 15
038      -        -45
039   X<0?      16-45
040    SF1   16 21 01
041   X<0?      16-45
042   GSB4      23 04
043    F1?   16 23 01
044   GTO2      22 02
045      1         01
046      6         06
047   RCL0      36 00
048    INT      16 34
049   X≤Y?      16-35
050    SF0   16 21 00
051   X>Y?      16-34
052   X⇄Y         -41
053   STO2      35 02
054   RCL4      36 04
055      1         01
056      3         03
057      6         06
058   GSBe   23 16 15
059      ÷        -24
060    INT      16 34
061   STO3      35 03
062   X>Y?      16-34
063   GTO8      22 08
064   X=Y?      16-33
065   GTO8      22 08
066   RCL3      36 03
067      1         01
068      3         03
069      6         06
070   GSBe   23 16 15
071      ×        -35
072   ST-4   35-45 04
073   RCL3      36 03
074   ST-0   35-45 00
075   GSB0      23 00
076   GSB4      23 04
077   GTO2      22 02
078  *LBL4      21 04
079    CF2   16 22 02
080      1         01
081   ST+1   35-55 01
082   RCLB      36 12
083   STO4      35 04
084   RCL1      36 01
085      1         01
086      -        -45
087   RCLC      36 13
088      ÷        -24
089   DSP4      -63 04
090    RND      16 24
091    FRC      16 44
092   X≠0?      16-42
093    RTN         24
094   RCLA      36 11
095   STO4      35 04
096    SF2   16 21 02
097    RTN         24
098  *LBL8      21 08
099   RCL2      36 02
100      1         01
101      3         03
102      6         06
103   GSBe   23 16 15
104      ×        -35
105   ST-4   35-45 04
106   GSB0      23 00
107    F0?   16 23 00
108   GTO3      22 03
109      1         01
110      6         06
111   ST-0   35-45 00
112   GTO2      22 02
```

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DABS Downlink ELM

113	*LBLd	21 16 14
114	1	01
115	2	02
116	.	-62
117	3	03
118	5	05
119	4	04
120	*LBLe	21 16 15
121	EEX	-23
122	6	06
123	÷	-24
124	RTN	24
125	*LBL3	21 03
126	GSB7	23 07
127	RCL4	36 04
128	X>0?	16-44
129	GTO1	22 01
130	X=0?	16-43
131	GTO1	22 01
132	GSB4	23 04
133	GSB7	23 07
134	GTO1	22 01
135	*LBL7	21 07
136	RCLi	36 45
137	GSBd	23 16 14
138	×	-35
139	1	01
140	8	08
141	6	06
142	GSBe	23 16 15
143	+	-55
144	ST-4	35-45 04
145	RTN	24
146	*LBL9	21 09
147	RCL1	36 01
148	1	01
149	-	-45
150	RCLC	36 13
151	÷	-24
152	STOI	35 46
153	INT	16 34
154	4	04
155	×	-35
156	RCLI	36 46
157	FRC	16 44
158	RCLC	36 13
159	×	-35
160	EEX	-23
161	2	02
162	CHS	-22
163	×	-35
164	+	-55
165	STOI	35 46
166	RCLA	36 11
167	RCLB	36 12
168	F2?	16 23 02
169	X⇄Y	-41
170	RCL4	36 04
171	-	-45
172	RCLI	36 46
173	+	-55
174	FIX	-11
175	DSP6	-63 06
176	RTN	24
177	*LBLA	21 11
178	5	05
179	STOI	35 46
180	0	00
181	STOE	35 15
182	1	01
183	RTN	24
184	*LBLB	21 12
185	STOi	35 45
186	RCLI	36 46
187	1	01
188	+	-55
189	STOI	35 46
190	RCLE	36 15
191	1	01
192	+	-55
193	STOE	35 15
194	1	01
195	+	-55
196	RTN	24
197	*LBL0	21 00
198	RTN	24
199	R/S	51

4. DABS SIMULATION MODEL

The DABS Simulation Model computes the average time in queue for all messages on the basis of a Monte Carlo generation of data traffic. Model inputs are the message arrival rate, the available time during each ATCRBS cycle, the average message service time, and the number of seconds per revolution.

Model inputs require modifying the actual program code in order to conserve data registers.

User instructions are as follows:

1. Enter the DABS Simulation Program and switch to PRGM mode.
2. Delete program step 91 and enter the mean service time for a message.
3. Delete steps 75, 72, 33, and 28. Replace each with the time in seconds for one revolution.
4. Delete step 25 and replace it with the time in seconds available for company communications transmissions during each revolution.
5. Delete step 19 and replace it with the time in seconds for one revolution.
6. Delete step 12 and replace it with the message arrival rate in messages per second.
7. Switch to RUN mode.
8. Enter a random number seed and depress "STO" and then "O". (The preferred seed is 0.5284163.)
9. Enter a "1" and depress "STO', "C", "STO", and "I".
10. Run the program by depressing "A".
11. Stop the program by depressing any key.
12. Depress "D" to obtain the mean time waiting and being served.
13. Depress "E" to obtain the simulated arrival rate for comparison with the desired arrival rate.
14. Continue the simulation by depressing "A".

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DABS Simulation

```
001  *LBLA      21 11
002   ISZI   16 26 46
003   RCL0      36 00
004      9         09
005      9         09
006      7         07
007      x        -35
008    FRC      16 44
009   STO0      35 00
010     LN         32
011    CHS        -22
012      0         00
013      ÷        -24
014   RCLA      36 11
015      +        -55
016   STOA      35 11
017   STOi      35 45
018  *LBL3      21 03
019      4         04
020   RCLA      35 11
021   RCLB      36 12
022      -        -45
023   X≤Y?      16-35
024   GTOA      22 11
025      0         00
026   STOD      35 14
027   RCLB      36 12
028      4         04
029      ÷        -24
030    INT      16 34
031    EEX        -23
032      +        -55
033      4         04
034      x        -35
035   STOB      35 12
036    F0?   16 23 00
037   GTO1      22 01
038  *LBL0      21 00
039   GSBa   23 16 11
040  *LBL1      21 01
041   RCLD      36 14
042   RCLE      36 15
043      -        -45
044   X<0?      16-45
045   GTO2      22 02
046    CF0   16 22 00
047   STOD      35 14
048   RCLB      36 12
049   RCLE      36 15
050      +        -55
051   STOB      35 12
052   RCLC      36 13
053    X⇄I      16-41
054   STOC      35 13
055    CLX        -51
056   RCLi      36 45
057      -        -45
058    P⇄S      16-51
059   ST+9   35-55 09
060    EEX        -23
061   ST+8   35-55 08
062    P⇄S      16-51
063   ISZI   16 26 46
064   RCLC      36 13
065    X⇄I      16-41
066   STOC      35 13
067   RCLI      36 46
068   X≠Y?      16-32
069   GTO0      22 00
070   RCLi      36 45
071   STO1      35 01
072      4         04
073      ÷        -24
074    INT      16 34
075      4         04
076      x        -35
077   STOB      35 12
078    EEX        -23
079   STOC      35 13
080   STOI      35 46
081   GTOA      22 11
082  *LBL2      21 02
083    SF0   16 21 00
084    CHS        -22
085   STOE      35 15
086   RCLB      36 12
087    INT      16 34
088   STOB      35 12
089   GTO3      22 03
090  *LBLa   21 16 11
091      0         00
092   STOE      35 15
093    RTN         24
094  *LBLD      21 14
095    P⇄S      16-51
096   RCL9      36 09
097   RCL8      36 08
098      ÷        -24
099    P⇄S      16-51
100    RTN         24
101  *LBLE      21 15
102    P⇄S      16-51
103   RCL8      36 08
104    P⇄S      16-51
105   RCLA      36 11
106      ÷        -24
107    RTN         24
108    R/S         51
```